MANAGEMENT OF
LIFE-THREATENING POLIOMYELITIS
Copenhagen 1952-1956

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MANAGEMENT OF LIFE-THREATENING POLIOMYELITIS

COPENHAGEN 1952-1956

WITH A SURVEY OF AUTOPSY FINDINGS IN 115 CASES

EDITED

BY

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PREFACE

NEARLY four years have now elapsed since the devastating epidemic of poliomyelitis in Copenhagen in 1952. This book, besides giving a short description of the main epidemiological features of the epidemic, deals with the many intricate clinical and therapeutic problems arising in life-threatening poliomyelitis.

Having in mind the formidable odds we were fighting against and the precarious way in which we fumbled through the maze of clinical, biochemical and therapeutic problems confronting us, it is our hope that this book may be of some help to others faced with the task of treating poliomyelitis at its worst.

I want to extend my sincere thanks to all my fellow workers, not alone to my co-authors but also to the many colleagues, nurses and medical students who worked so hard and so well during the epidemic and the years after. My thanks also go to the hospital authorities of Copenhagen and to The Danish National Association for Infantile Paralysis whose generous grant made the preparation of this book possible.

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Blegdam Hospital, Copenhagen.
June 1956.

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BY

H. C A. LASSEN

IN 1952 the metropolitan area of Copenhagen was struck by an epidemic of poliomyelitis unprecedented in severity in the history of Denmark. As in the other Scandinavian countries several large epidemics had raged in our country in the past but the 1952 epidemic surpassed all previous experience not alone by its size but even more so by the high incidence of involvement of the upper part of the central nervous system. From the beginning of August to the end of the year nearly 3,000 patients with a diagnosis of poliomyelitis were admitted to the Blegdam Hospital and in 2,241 the diagnosis was verified Of a total of about 1,250 cases with paralysis no less than 345 had insufficiency of respiration or impairment of swallowing or both, and required special treatment

The optimal treatment of bulbar and respiratory poliomyelitis is one of the most intricate therapeutic problems in the whole field of medicine, especially because of the all-important significance of the time factor Essentially it is a respiratory problem of maintaining an open airway and securing adequate oxygenation and carbon dioxide elimination If ventilation is reduced the margin between life and death may be very narrow Resolute therapeutic action will often decide the issue

When in 1952 we were faced with the catastrophe we certainly were inadequately prepared to cope with the situation, and although we thought we knew something about the management of bulbar and respiratory poliomyelitis, it soon became clear that only very little of what we did know at the beginning of the epidemic was really worth knowing During the previous fifteen years we had treated more than a hundred patients with bulbar and respiratory poliomyelitis, mostly in cuirass respirators But invariably the results had been very unsatisfactory with a mortality rate always in the vicinity of eighty per cent This had been the case even after the introduction in 1948 of early tracheotomy.



FIG. 1
Map of Greater Copenhagen showing distribution of cases.

During the height of the epidemic, patients with bulbar and respiratory poliomyelitis came pouring into the Blegdam Hospital. For many weeks we received thirty to fifty patients daily, of whom six to twelve were desperately ill with respiratory insufficiency and impairment of deglutition, drowning in their own secretions.

Our hospital has about 500 beds and serves as a polio treatment centre for the metropolitan area of Copenhagen with a population of 1,200,000 people (Fig 1). At our disposal we had only one tank and six cuirass respirators, a meagre supply of equipment which was soon exhausted. During the first few weeks of the epidemic our results were just as discouraging as formerly. As the situation became worse we were soon faced with the intolerable dilemma of having to choose which patient to treat in the few respirators at hand and which not to treat, we were therefore forced to seek new ways of ventilating our patients. The need for improvisation became imperative

As we felt that the application of modern principles of anaesthesia to the problem of obstructed airways and respiratory insufficiency in poliomyelitis might improve our results anaesthetists were invited to join our staff, the first being Dr Bjørn Ibsen. Special teams of poliomyelitis specialists, laryngologists and anaesthetists were set up, and on August 26 the first patient was treated with the method which soon became our method of choice in patients with impairment of swallowing and reduced ventilation—namely, tracheotomy just below the larynx with insertion of an inflatable rubber cuff tube into the trachea, frequent suction of the airway, probably repeated bronchoscopy, postural drainage and manual positive pressure ventilation (bag ventilation) with insufflation of a mixture of oxygen and nitrogen.

This simple method, with an equipment easy to procure and easy to standardise, proved of great value in the circumstances and saved many lives

CHAPTER I

SURVEY OF THE EPIDEMIC

BY H C A LASSEN

IN 1952 Denmark had a population of 4,300,000 people with no less than 1,200,000 (twenty-eight per cent) in the metropolitan area of Copenhagen

TABLE I

POLIOMYELITIS IN DENMARK, 1952

	Total number of cases	Paralytic No	Paralytic per 100,000	Non-paralytic No	Non-paralytic per 100,000
Entire country	5,676	2,450	56	3,226	52
Copenhagen	2,899	1,280	105	1,619	133

Table I shows the cases of poliomyelitis notified in Denmark in 1952 (Hamtoft, 1953). The Copenhagen area with about one fourth of the population had just over one half of all cases, paralytic as well as non-paralytic. The attack rate of paralysis was here 105 per 100,000 inhabitants, a very high attack rate indeed For paralytic and non-paralytic cases the attack rate was 238 per 100,000, a figure far exceeding the figures for the three big epidemics in the United States of America in 1952 and in Sweden in 1953. Only the island of Bornholm in the Baltic had higher attack rates than the Capital as a whole, but in one of the three districts of the metropolitan area the attack rate of paralytic disease went up to 169. It is indeed doubtful whether any city of the size of Copenhagen has ever experienced an outbreak of similar magnitude

The attack rates presented in Table II are extremely high particularly in the age groups from one to nine years and especially in the metropolitan area, where the incidence of paralysis in male children between one and four years rose to the formidable figure of nearly 600 per 100,000, i e more than one in two hundred. After the age of nine there is a sharp fall but in the age groups from fifteen to twenty-nine years the attack rates are again comparatively high, especially in

TABLE II

PARALYTIC POLIOMYELITIS IN RELATION TO AGE AND SEX.
(RATES PER 100,000 INHABITANTS)
(HAMTOFT, 1953)

Age	Entire country		Copenhagen		Entire country outside Copenhagen	
	Male	Female	Male	Female	Male	Female
Under 1 year	99	106	248	255	49	58
1 to 4 years	277	226	592	445	157	149
5 to 9 ,,	169	121	324	251	118	77
10 to 14 ,,	55	40	114	78	38	29
15 to 19 ,,	38	62	65	134	31	40
20 to 24 ,,	37	54	56	86	30	40
25 to 29 ,,	46	66	84	118	30	42
30 to 44 ,,	27	28	47	50	18	16
45 years and over	3	2	3	2	3	2

Copenhagen. For unknown reasons in the younger age groups the figures for boys are constantly higher than the corresponding figures for girls, but from fifteen to thirty years women have higher attack rates than men, presumably because of their more intimate contact with small children, who seem to be the most active disseminators of the disease (Lindahl)

TABLE III

DEATHS FROM POLIOMYELITIS IN 1952 PER 100 PARALYTIC CASES
(FATALITY RATE PER CENT.)
(HAMTOFT, 1953)

Age	Entire country		Copenhagen		Entire country outside Copenhagen	
	Male	Female	Male	Female	Male	Female
Under 1 year	17.5	9.8	8.0	8.3	33.3	11.8
1 to 4 years	8.2	5.1	6.7	3.0	10.5	7.3
5 to 14 ,,	9.1	7.2	5.6	6.1	12.3	8.4
15 to 64 ,,	22.9	12.4	22.7	8.2	23.0	17.4

The fatality rates for the whole country (Table III) are higher for males than for females in all age groups, but this is not the case in

Copenhagen, where among the children only those from one to four years show this tendency. Above fifteen years the male sex succumbs two to three times as often as the female—why, we do not know. The strikingly high mortality rate of 23 per cent. in adult men with paralysis illustrates the extraordinary severity of the epidemic. Yet, in all groups except this adult male group the rates were considerably lower in the Capital than in the rest of the country. The overall

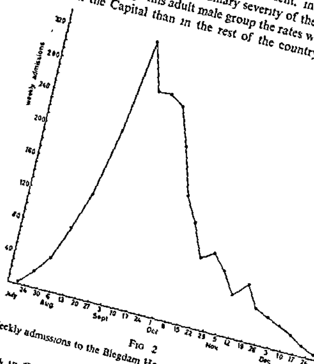


Fig. 2

Weekly admissions to the Blegdam Hospital of cases of poliomyelitis in 1952

mortality in Copenhagen of patients with paralysis was 8.2 per cent. against 13.5 per cent. in the rest of the country. This presumably was due to the new methods of treatment used in the Blegdam Hospital.

Between July 24 and the end of the year 2,830 patients were admitted to our hospital with a diagnosis of poliomyelitis. In 2,241 of these the diagnosis was verified, while 589 cases did not meet our diagnostic criteria. We had 1,235 paralytic and 1,006 non-paralytic patients. All the non-paralytic had pleocytosis of the spinal fluid.

In about twenty of the Copenhagen cases the State Serum Institute demonstrated the presence of poliomyelitis virus either in the stools or in autopsy material from the central nervous system. Type I (Brünhilde) alone was found in all cases. There was no simultaneous Coxsackie infection.

Special therapeutic measures, such as tracheotomy, artificial respiration, postural drainage or a combination of these were required in 345 of the 1,235 paralytic cases. The enormous load of severely ill patients is well illustrated by the fact that in four months we treated three times as many cases with respiratory insufficiency, paralysis of the ninth, tenth and twelfth cranial nerves and polio-encephalitis as in the preceding ten years. At times we had seventy patients requiring artificial respiration. Now, more than three years later, twenty-five patients, still requiring respiratory assistance, remain in hospital.

Fig. 2 shows that the epidemic reached its peak about Sept. 1. During the week of August 28–Sept. 3 our hospital admitted 335 patients or nearly fifty cases daily. The ascending branch of the epidemic curve was alarmingly steep, the descending branch—as usual—more drawn out. In fact, it did not reach the base line until April 1953. As the epidemic went on, the ratio of paralytic to non-paralytic cases grew steadily, but as a whole it was about 1 : 1. It will be appreciated, of course, that the number of patients admitted with non-paralytic poliomyelitis does not give an accurate picture of the true incidence of such cases in the epidemic area.

CHAPTER II

CLASSIFICATION OF 345 CASES OF LIFE-THREATENING POLIOMYELITIS

By J Pedersen, M Bjorneboe, S Johnsen, H Reiter, E. Skinhoj and T Sottrup

GENERAL ANALYSIS OF THE SERIES

During the eight months, July 7, 1952, to March 2, 1953, paralysis of respiratory muscles or of swallowing was diagnosed in 345 patients with poliomyelitis and constituted a definite threat to the life of those concerned.

The diagnostic criteria of respiratory failure and pharyngeal-laryngeal paralysis which we adopted were as follows·

Respiratory failure

1. Patients with cyanosis and dyspnoea
2. Patients with reduced or paradoxical respiratory excursion
3. Patients with hypercapnia or a vital capacity less than fifty per cent
4. Patients with accumulation of secretions in the air passages proper (obstruction)

Pharyngeal-laryngeal paralysis

Paralysis of the pharyngeal or laryngeal musculature was ascertained by direct observation by the otolaryngologist

A total of 333 cases—79 with and 254 without pharyngeal-laryngeal paralysis—met one or more of the four criteria set up for respiratory failure, the remaining twelve cases were diagnosed as having impairment of deglutition without respiratory insufficiency (Table IV).

Generally, there is no particular difficulty in differentiating frank respiratory from non-respiratory paralysis. But in borderline cases there is naturally a certain margin for subjective judgment, which causes some uncertainty when comparing series of cases which have been treated according to different principles As an illustration of our assessment of this series, it may be mentioned that 83 per cent. of our patients with respiratory failure had to have artificial ventilation.

TABLE IV

DISTRIBUTION OF RESPIRATORY PARALYSIS AND PARALYSIS OF SWALLOWING IN 345 CASES OF LIFE-THREATENING POLIOMYELITIS

		Respiratory failure		Total
		+	—	
Pharyngeal–	+	79	12	91
laryngeal paralysis	—	254	—	254
	Total	333	12	345

It may be more difficult to decide whether pharyngeal paralysis is present in a given case, especially when the patient is mentally hazy or markedly exhausted or, of course, after the institution of therapy including tracheotomy, artificial ventilation and tube feeding. By our definition of pharyngeal-laryngeal paralysis we have included all cases in which failure of swallowing was diagnosed, although some relatively mild and temporary cases may not have been noticed. However this uncertainty is of no special prognostic importance as the case mortality of respiratory insufficiency in our series is independent of the presence of pharyngeal paralysis.

TABLE V

SEX AND AGE DISTRIBUTION OF 345 PATIENTS WITH LIFE-THREATENING POLIOMYELITIS

Age	Male	Female	Total
<15 years	108	72	180 (<1 year: 6)
≥ 15 years	88	77	165 (>40 years: 12)
Total	196	149	345

Table V gives a survey of the sex and age distribution of the 345 patients with life-threatening poliomyelitis The number of adults is almost as high as that of children. In this respect, the severe cases differ from the epidemic in general.

The fatality rate was greatest for men, about 55 per cent., lower for women, girls and boys, being about 34 per cent. for each of these three groups.

CLASSIFICATION OF THE SERIES

A good classification, besides being fairly simple, should say something essential about the prognosis and serve as a guide to therapy, it should be made on an objective basis, and if possible be unequivocal and easy to employ.

At present it is difficult to set up a satisfactory classification—anatomical or clinical—of a series such as that with which we are dealing. A main obstacle to applying the usual anatomical classification is the fact that the poliomyelitis process does not keep within the arbitrary anatomical boundaries of the central nervous system, but may spread in any direction—and indeed may become disseminated.

TABLE VI(a)

MAIN CLASSIFICATION OF THE SERIES. DISTRIBUTION AND MORTALITY

Group	Clinical Groups	Principal site of anatomical lesion	Distribution		Deaths	
			No	%	No	Fatality Rate %
A	Polioencephalitis	*Encephalo-bulbar*	75	22	29	39
B	Pharyngeal and/or laryngeal paralysis without encephalitis, cerebralia or spinal paralysis	*Bulbar*	12	4	3	25
C	Paralysis of respiratory mm without encephalitis, cerebralia or pharyngeal paralysis	*Spinal*	157	45	50	32
D	Paralysis of respir mm and pharynx or larynx without encephalitis or cerebralia	*Spino-bulbar*	28	8	13	46
E	Paralysis of respir mm combined with cerebralia without pharyngeal paralysis	*Spino-(bulbar-) cerebral*	60	17	38	63
F	Paralysis of respir mm and pharynx or larynx combined with cerebralia	*Spino-bulbar-cerebral*	13	4	11	85
		Total	345	100	144	42

mm. = muscles

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mm = muscles

But even when a correct anatomical diagnosis is possible—e g spinal muscular paralysis—the term covers a morbid condition varying from a relatively mild to a very severe illness. Further it is often difficult at the bedside to interpret definite clinical signs correctly, e.g. whether or not unconsciousness is due to the disease process proper (polioencephalitis) or to different complications (anoxaemia, hyperpyrexia, etc.).

On account of these difficulties we have adopted a mixed clinico-anatomical classification in an attempt to keep the individual groups homogeneous.

Our main classification includes six groups each of which comprises from 4 to 45 per cent. of the total. The mortality is seen to vary from 25 to 85 per cent. (Table VI(a))

In order to facilitate description and discussion it has been thought advisable to reduce the number of groups. This may be done in various ways—according to the purpose. The one here employed has proved practical in respect of the different complications (Table VI(b)).

TABLE VI(b)

SUMMARY OF TABLE VI(a)

Groups	Principal site of anatomical lesion	Distribution		Mortality	
		No.	%	No	%
C+D	*Encephalobulbar*	87	25	32	37
A+B	*Spinal (bulbar)*	185	54	63	42
E+F	*Spino (bulbar) cerebral*	73	21	49	67

GROUP A: *Polioencephalitis*

The most distinct and most constant symptom in this group was haziness of consciousness, which in many cases was, or became, very pronounced, eventually developing into coma. This naturally led to stagnation of secretions in the air passages (the presence of which further reduced the respiratory capacity) and impairment of swallowing. In true polioencephalitis—in contradistinction to cloudiness of consciousness due to the complications mentioned below—the symptoms always commence from 'above' and move caudally—in other words the first manifestations are of diffuse encephalitis.

Many of the patients in group A presented a type of respiratory insufficiency which in essential points differed from the usual spina

respiratory paralysis and from respiratory insufficiency due to pulmonary obstruction These patients 'forgot' to breathe, so that long pauses of apnoea resulted. Now and again the patients would breathe rather regularly, and occasionally take even very large and deep inspirations so, that the respiratory muscles were seen to function normally. It therefore seems reasonable to assume that the muscle function was intact.

It was also a striking and characteristic feature that this type of respiratory failure proved susceptible to verbal stimulation by the nursing personnel, the patients reacted to such stimulation with forced breathing, after which—when left to themselves—they repeatedly fell back into their usual hazy state of mind. This susceptibility to verbal stimulation, we think, makes it justifiable to speak of a special encephalitic type of respiratory paralysis A similar type of respiratory paralysis has been noticed by others and termed central respiratory paralysis. (Sarnoff *et al* 1951, Wilson, 1952, Galloway & Elsen, 1951)

This polioencephalitic group is, we think, fairly homogeneous, because by definition patients in whom cerebral symptoms may be due primarily to other causes—*e g* hyperpyrexia, anoxaemia, hypercapnia and uraemia—are excluded.

As will be noticed from Table VI(a), we adopted a concept designated as 'cerebralia' This term is used to denote a pronounced, but not primary, defect of consciousness or frank coma lasting at least for forty-eight hours All such patients presented extensive spinal paralysis which was observed before the diffuse cerebral symptoms developed In these cases the disease process started from 'below' and the symptoms and signs of cerebral involvement were due in particular to anoxic, hypercapnic, hyperpyretic and uraemic injuries It is appreciated of course that the possibility of actual viral damage could not be excluded, because we were not always able correctly to interpret the complex aetiology of 'cerebralia' As a result, whereas the term encephalitis bears a rather specific sense, the term cerebralia is useful in denoting a non-specific condition which may arise from a variety of causes

Cranial nerve paralysis was found very frequently in group A, mainly of the upper cranial nerves and, in particular, of the facial nerve Most of the motor cranial nerve palsies were represented One patient for example had bilateral total paralysis of the fifth nerve and presented a clinical picture both rare and ghastly. Pharyngeal

paralysis was present in thirty-eight of the seventy-five patients entered in group A.

Paralysis of the eye muscles was very frequent and the clinical effects were highly variable. Besides nuclear paralysis (III, IV and VI), all degrees of nystagmus in any direction were seen repeatedly, as well as shifting eyes and true opsoclonia.

It is often impossible to decide at once whether patients with polioencephalitis are also afflicted with paralysis of spinal origin, because deep cerebral muscular hypotonia may be present, localised to a single muscle group or, more frequently, widespread. A diagnostic aid may here be found in the characteristic feature that polioencephalitis patients often emerge rather abruptly from the comatose state. They suddenly open their eyes, breathe normally, move their extremities, and are well—apart perhaps from the presence of nuclear cranial nerve paralysis. Consequently group A includes many patients who attain complete recovery under proper treatment, the polioencephalitis leaving neither somatic nor mental sequels.

It is remarkable that group A almost exclusively comprises children and that there are twice as many boys as girls (Tables VII(a) and VII(b)). In this respect it differs distinctly from the other groups. Owing to the occurrence of pseudo-paralysis which has been mentioned previously considerable difficulties are encountered in establishing with certainty in the acute stage the incidence of true spinal paralysis in the patients in group A. Rather to our surprise we found that the polioencephalitis group has one important distinguishing feature namely *that these patients do not develop hypertension.*

GROUP B: *Patients with pharyngeal or laryngeal paralysis but no cerebralia or spinal paralysis*

This is a small group which includes the 12 patients who had pure pharyngeal or laryngeal paralysis.

In the series as a whole there were 91 patients with verified pharyngeal or laryngeal paralysis (Table IV). The remaining 79 patients are entered in groups A (38), D (28) and F (13).

GROUP C: *Patients with spinal respiratory insufficiency—without encephalitis, cerebralia or pharyngeal paralysis*

This group is entirely clear-cut and includes no patients with bulbar poliomyelitis

The mortality experienced by this group should be considered by reference to Table VII(a), which shows that no less than 78 per cent. of the patients had bilateral paralysis of the upper-extremities, often of a very severe degree. This fact in itself indicates how severe was

TABLE VII(a)

DISTRIBUTION OF SEX, AGE, BILATERAL PARALYSIS OF UPPER EXTREMITIES AND OBSTRUCTION OF AIR PASSAGES

(345 cases)

Group	Total No of cases	Age and Sex				Bilateral paralysis of upper extremities		Obstruction of air passages	
		Under 15 years		15 years and more					
		M	F	M	F.	No.	%	No.	%
A	75	44	20	3	8	4	5	25	33
B	12	7	2	2	1	0	0	4	33
C	157	34	34	46	43	122	78	45	29
D	28	4	3	9	12	19	68	8	29
E	60	18	11	20	11	53	88	14	23
F	13	1	2	8	2	9	69	5	38
Total	345	108	72	88	77	207	60	101	29

the poliomyelitis process in the spinal medulla in the 1952 epidemic. Table VII(a) further shows that the sex ratio in this group was 1 · 1, and that adult patients outnumbered the children but slightly.

GROUP D *Patients with paralysis of respiratory muscles and of the pharynx or larynx, but without encephalitis or cerebralia*

This group is clearly defined and requires no particular comment.

GROUP E *Patients with paralysis of respiratory muscles and cerebralia but without pharyngeal paralysis.*

Apart from the fact that pharyngeal paralysis was not present, this group is identical with group F.

GROUP F *Patients with paralysis of respiratory muscles, pharynx and or larynx and with cerebralia*

This is a small group easy to define. It is best characterized by the designation "total paralysis," and is all the more alarming

because the development may take place with catastrophic rapidity. Mortality approaches 100 per cent.

Groups E+F thus cover the most severe cases of poliomyelitis, with bilateral paralysis of the upper-extremities in the great majority (85 per cent.) of the cases. Here in particular are met such dangerous factors as shock, hyperpyrexia, etc. The significance of cerebralia in determining the death of patients with severe spinal paralysis of the respiratory muscles is well portrayed in Table VI(a), (groups E and F).

From Tables VII(a) and (b) it will be noticed that there is a preponderance of males in these groups, and more adults than children.

TABLE VII(b)

SUMMARY OF TABLE IV(a)

Groups	Total No of cases	Age (in years) and Sex				Ratio		Bilateral paralysis of upper extremities		Obstructi of air pa sage (befor tracheotomy	
		under 15		15 and more		Age (in years)	Sex				
		M	F.	M	F	<15 >15	M F.	No.	%	No	%
A+B	87	51	22	5	9	5 2 1	1 8.1	4	5	29	33
C+D	185	38	37	55	55	1.1 5	1·1	141	76 } 79	53	29
E+F	73	19	13	28	13	1 1 3	1 8:1	62	85 } 79	19	26
Total	345	108	72	88	77	1 1.1	1·3 1	207	60	101	29

From Tables VII(a) and (b) it is evident that stagnation of secretions in the air passages is about equally frequent in all groups.

The fact that our series includes such a great number of patients with clear-cut paralysis of the respiratory muscles and patients with stagnation of secretions in the air passages, is presumably explained by two circumstances· first, that many of them were already in an extremely serious condition at the time of hospitalisation, and second that, even before treatment could be instituted they had gone through episodes of hypoxia and CO_2 retention with a resulting increase of secretions

As a further illustration of the severity of the disease in these 345 cases it may be mentioned that in 33 (22 per cent) of the 144 fatal cases death occurred within twenty-four hours after admission. No

less than twenty-four (17 per cent.) were completely non-paralytic on admission, and in ten the disease terminated fatally within the first three days. Finally four patients were already dead when they reached the hospital.

TABLE VIII

COURSE OF RESPIRATORY PARALYSIS IN 277 CASES GIVEN ARTIFICIAL RESPIRATION

Period	Died	Living	
		Artificial respiration	
		+	−
Within 1 week	97	160	20
At end of 1 month	130	102	45

In Table VIII a schematic survey is given of the course of the disease within the first month for all patients, treated with artificial ventilation, a total of 277. Of these 97 died within the first week, and only 20 of the remaining 180 had by this time regained spontaneous respiration. Four weeks after admission the number of deaths had increased to 130, and of the surviving 147 patients, 102 still required complete or partial artificial ventilation, while 45 were back on spontaneous respiration. Thus at this time no less than 130—about one half—had died, while 102—a good third—were still on artificial ventilation and 45—one sixth—had regained spontaneous respiration.

CHAPTER III

THE ANAESTHETIST AND POSITIVE PRESSURE BREATHING

BY BJORN IBSEN

IN the last week of August 1952 the poliomyelitis situation in Copenhagen had become critical. During the first phase of the epidemic the results had, as usual, been very poor. Of thirty-one patients treated in respirators, twenty-seven died during the first three weeks of August.

Judging from the clinical condition of patients in tank or cuirass respirators, there could be no doubt that they were severely underventilated and very often had accumulation of secretions in the air passages with or without the production of atelectasis. These dangerous complications could not be abolished by postural drainage or by aspiration from the pharynx. Obviously the treatment of bulbar poliomyelitis required revision and reorganisation. First of all it was necessary to find out which symptoms were due to inadequate ventilation, and which were due to the disease itself.

CLINICAL DEMONSTRATION OF A CASE

An attempt was made to demonstrate on a patient how adequate ventilation could be administered without the help of a respirator.

The first patient was a girl, twelve years old, in a very bad condition, with paralysis of all four extremities. She also had atelectasis of the left lung, and was lying on her side in the Trendelenburg position, gasping for breath and drowning in her own secretions. Her temperature was 40·2° C. (104·4° F.). She was cyanotic and sweating.

Tracheotomy was done immediately under local anaesthesia, and a cuffed endotracheal tube introduced. During this procedure the patient became unconscious. A to-and-fro absorption system was connected directly with the tracheal tube, and thorough endotracheal suction was performed. Even when this had been done, however, it was still impossible to inflate the lungs, partly because of secretions,

partly due to bronchospasm. She was therefore given 100 mg of pentothal intravenously in the hope that this might stop her struggling She immediately collapsed; her own respiration stopped; but the lungs could now be inflated. Shortly after this a Brinkman carbovisor and an oximeter of the Millikan type were applied. These quickly demonstrated that a substantial accumulation of CO_2 can arise even when full oxygenation of the blood is maintained with pure oxygen. The usual clinical signs of CO_2 retention could now be recognized There was a rise in blood pressure, the skin became clammy and sweaty and the patient started breathing without help although her respiration soon became gagging and bucking. Secretions began to pour out of her nose and mouth.

These symptoms could be relieved within a few minutes, when CO_2 was removed by increasing the ventilation. But, as soon as the CO_2 surplus was eliminated, the systolic blood pressure dropped to 80—and the girl appeared to be in shock. A blood transfusion was given which improved her condition remarkably and she soon became warm, dry and pink

The patient was now put in a cuirass respirator All the signs of underventilation returned and she again became cyanosed. Administration of oxygen in the same way as to the other patients in respirators revealed that her colour could be improved and nearly full oxygenation ensured—but the carbovisor showed a continuous rise in CO_2. When the respiration was assisted in the respirator by intermittent squeezing of a bag connected with the tracheotomy tube, everything went well again

Study of this patient had thus shown that it might be necessary to continue the manually assisted respiration because it was impossible for the respirator to maintain a ventilation sufficient to secure the necessary elimination of CO_2 It had also served to demonstrate that theoretical considerations could be applied to treatment and that some of the symptoms were simply due to inadequate exchange of gases across the pulmonary membrane. Respiratory complications rather than the primary disease process were responsible for many of the difficulties

In this way three main principles of treatment could be defined, namely the need to maintain a free airway, adequate support of the ventilation, and when necessary the treatment of shock.

The best way to prevent pulmonary complications is to avoid the accumulation of secretions which produce them. The most effective

way of securing this is to perform a tracheotomy. Now this had been done a number of times since 1948 in the Blegdam Hospital but usually as a late emergency measure under local anaesthesia. The operation itself was difficult because as a rule the patient was already apprehensive and non-cooperative—presumably on account of anoxia. On handling the trachea, the state of anoxia was further aggravated because of spasm and vomiting and aspiration of secretions were additional hazards. An emergency tracheotomy performed so late in the disease is in our opinion always likely to fail.

These factors emphasized the need to have an endotracheal cuffed tube passed through the mouth before the operation was begun in order to secure a free airway. Naturally, general anaesthesia was usually essential before this could be done. The surgeon was thus enabled to work undisturbed. Bleeding could be effectively controlled before the tracheotomy tube was inserted. Such a sequence of procedures seemed to hold a promise of improved results.

The experience gained from the demonstration described above, and a consideration of the complications arising during emergency tracheotomy under local anaesthesia, resulted in the adoption of the following broad principles as a first approach to the treatment of life-threatening poliomyelitis

1. Any period of anoxia should be avoided.
2. When necessary a tracheotomy should be performed, and a cuffed endotracheal tube inserted in order to protect the lungs from aspiration of secretions from above, to permit effective endotracheal suction and thus to secure a free air passage.
3. The tracheotomy should be preceded by oral intubation. As a rule this should be done under general anaesthesia.
4. Assistance to inadequate spontaneous ventilation should be given when necessary, by connecting the tracheotomy tube with a to-and-fro absorber system, and then manually performing intermittent positive pressure ventilation, or by using special machines designed for intratracheal positive pressure ventilation.
5. Shock should be treated according to the usual principles.

In consequence of the adoption of these principles it was decided to transfer all patients with respiratory problems to a special department. The decision would be made when one or other of the following danger-signals was observed:

Difficulty in swallowing
Accumulation of secretions in the airway
Weak and insufficient coughing—arising from paralysis of the intercostal muscles or, especially, of the diaphragm
Paralysis of the upper extremities
Progressive ascending paralysis
Marked encephalitic signs

In the observation ward the condition of the patient was followed closely and the indications for the different types of treatment were estimated. The following is a rough guide to illustrate the line followed.

Patients were divided into *wet* and *dry* cases, referring to the presence or absence of secretions in the airway. These two groups were further subdivided according to whether or not the respiratory muscles seemed able to secure an adequate exchange of gases when a free airway was maintained.

The few *dry* cases with sufficient ventilation were simply kept under observation. The *dry* cases with insufficient ventilation were, in the first place, usually placed in a tank or cuirass respirator in order to give them a chance to get through without tracheotomy. Only too often this was not possible.

The *wet* cases which seemed to have sufficient muscle power to maintain adequate ventilation were placed in postural drainage in an attempt to clear the airway. Very often, however, a tracheotomy had to be performed, especially in children whose cooperation for suction was poor and in whom the drainage posture was difficult to maintain.

The *wet* cases, with insufficient ventilation, were at once submitted to tracheotomy and artificial respiration. As a rule we did not dare to put wet cases in respirators without a preceding tracheotomy. On the few occasions when this was done it was always regretted

In any case where we were in doubt as to whether the impaired respiration was mainly due to secretions or to decreased ventilatory muscle power a tracheotomy was performed When the airway had been made as free as possible the decision had then to be made whether to leave the patient on postural drainage or to begin artificial respiration In most patients artificial respiration was required

The choice of anaesthetic for the operation was difficult. Pentothal and scoline were used in the beginning of the epidemic Later on cyclopropane was preferred No premedication was given—not even

atropine. Very often the patient stopped spontaneous breathing as soon as oxygen was given—and had to be anaesthetized by squeezing the cyclopropane down into the lungs.

The first hour after tracheotomy was always a most critical one. The reflexes were often rather vigorous and signs of incipient pulmonary oedema only too frequently present. We were therefore always rather afraid to give intravenous fluids during this period.

Manual artificial respiration was performed with a to-and-fro absorber system using a mixture of fifty per cent. nitrogen and fifty per cent. oxygen at a flow-rate of at least five litres per minute. Such a system was chosen in the hope that it might overcome the following difficulties:

1. Should the absorber work inefficiently the high flow-rate made the development of a CO_2 excess less likely.
2. Oxygen poisoning was unlikely to occur.
3. A slight excess of oxygen might have some effect in counteracting shock and might be useful when pulmonary complications were already present.
4. The high flow-rate might prevent the possibility of a low inspiratory oxygen from rebreathing.

It might be worth pointing out that this simple system had the advantage that the absence of complicated valves would prevent trouble arising from that cause. Finally the possibility of drying of the mucous membranes might be reduced since some condensed water would be present in the breathing bag.

In this way modern anaesthetic principles were brought to bear upon a problem which seemed at first sight outside the anaesthetist's range.

CHAPTER IV

THERAPEUTIC INDICATIONS

BY M. BJORNEBOE, S. JOHNSEN AND E. MOLTKE

IN recent years the therapeutic indications in bulbar poliomyelitis have been subject to significant alterations. Tracheotomy is now used extensively and positive pressure ventilation through a tracheal cannula has been adopted as a method of treatment.

In bulbar poliomyelitis the primary objects of therapy are to keep the air passages free, to afford sufficient ventilation and to ensure adequate nutrition. Although it may be divided into the treatment of swallowing insufficiency and the treatment of respiratory paralysis, in practice, these problems will often merge one into the other.

PATIENT MATERIAL

As described before, from August 26, 1952, the therapeutic regimen was altered on account of the very poor results obtained before that date. This chapter deals only with the 318 patients treated according to the new therapeutic principles.

On the basis of clinical observation the patients have been divided into two main *functional* groups (Fig. 3)

1 Patients with accumulation of secretions in the pharynx or air passages or both—*wet* cases, with respiratory paralysis and sometimes also paralysis of swallowing

2 Patients without secretions in the pharynx and air passages, the *dry* cases, with respiratory paralysis.

One, or more often, a combination of the following methods of treatment were employed

1 tracheotomy with positive pressure ventilation
2 tank or cuirass respirator
3 postural drainage
4. tracheotomy alone

It should be kept in mind that throughout the epidemic only a very limited number of mechanical respirators were at our disposal. One of the advantages of tracheotomy with positive pressure ventilation was that it was immediately available to any number of patients.

From Fig. 3 it is evident how the two main groups were treated. It will be observed that tracheotomy and positive pressure was employed in the majority of cases The mechanical respirators played only a minor rôle even in the treatment of pure spinal respiratory insufficiency.

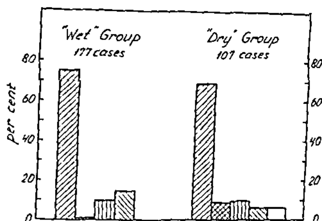


FIG. 3

Distribution of therapeutic measures in patients with life-threatening poliomyelitis belonging to the *wet* and *dry* groups *

- tracheotomy + positive pressure ventilation
- respirator (tank or cuirass) as only form of treatment
- postural drainage as only form of treatment.
- tracheotomy alone
- no particular treatment

Presumably the therapeutic principles adopted for the first main group, the *wet*, will be generally acknowledged, *i e.* tracheotomy and positive pressure ventilation in most cases It is a well-known fact that tank or cuirass respirators are not effective in respiratory insufficiency with accumulation of secretions in the air passages.

Nor is the treatment of the group with pure swallowing paralysis likely to give rise to discussion. As to the treatment of the other

* 34 of the 318 patients mentioned on p 19 have been left out 12 because they had only pure impairment of swallowing and 22 because an urgent tracheotomy had to be done immediately after their admission

main group, the *dry*, however, undoubtedly many clinicians will think that mechanical respirators should have been employed to a greater extent.

In order to throw some additional light on the question whether tracheotomy and intratracheal positive pressure ventilation were in

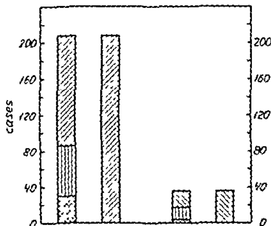


Fig 4

Change of treatment from postural drainage or respirator to employment of tracheotomy and positive pressure ventilation, or tracheotomy alone.

The two columns to the left illustrate initial and final treatment of patients eventually treated with tracheotomy and positive pressure ventilation The two smaller columns to the right illustrate initial and final treatment in patients eventually treated with tracheotomy (without positive pressure ventilation)

- tracheotomy + positive pressure ventilation.
- respirator (tank or cuirass) as only form of treatment.
- drainage as only form of treatment
- tracheotomy alone.

fact employed too frequently, we have ascertained in how many patients some other form of treatment was instituted primarily, and in whom the development of the disease necessitated employment

of a more radical procedure—tracheotomy and intratracheal positive pressure ventilation—in order to avoid death from suffocation.

Fig 4 gives a survey of all the patients treated with tracheotomy and positive pressure ventilation. The two columns to the left illustrate the initial and final treatment in the 208 cases, eventually given positive pressure ventilation. Almost one half of these patients were treated first with some other method, postural drainage or respirator (tank or cuirass) before the more radical method was employed. In this group sixty patients were *dry* at the beginning Of these four were first treated with postural drainage and twenty-one in tank or cuirass respirator.

The two smaller columns to the right illustrate the initial and the final treatment employed in the thirty-six cases, eventually treated with tracheotomy (without positive pressure ventilation). One half of these patients started with postural drainage or respirator treatment

In analysing the material it was found that two thirds of the patients initially treated with postural drainage and three fourths of those primarily treated in respirators had subsequently to submit to tracheotomy.

The fact that we tried as far as practicable to avoid tracheotomy may be emphasized by stating that some of the thirty-four patients in whom postural drainage was instituted as the only form of treatment, presented symptoms of incipient respiratory insufficiency at some time or other.

Postural drainage as the only form of treatment, of course, was continued only when by this means it was possible to reduce obstruction *without jeopardizing the ventilation.* Anoxaemia—even of brief duration—must always be avoided

The therapeutic indications adopted may be summarized as follows:

1. Respiratory and swallowing insufficiency with accumulation of secretions in the airway (*wet* cases) tracheotomy+positive pressure ventilation

2 Clear-cut respiratory insufficiency. (*a*) in a few very mild cases, no treatment; (*b*) respiratory insufficiency without accumulation of *secretions in the airway (dry cases).* body or cuirass respirators; (*c*) respiratory insufficiency with accumulation of secretions in the airway (*wet* cases) tracheotomy and positive pressure ventilation.

3. Pure swallowing paralysis *(wet cases): postural* drainage, sometimes followed by tracheotomy

CHAPTER V

BASIC MECHANICS OF ARTIFICIAL VENTILATION

BY C. RATTENBORG

LUNG MODEL EXPERIMENTS

IN artificial ventilation the respiratory air flow is actuated by variations in pressure· the inspiration being active, the expiration more or less passive.

Changes of volume of the lungs can be brought about artificially in four different ways:

1. intrapulmonary positive pressures
2. extrathoracic negative pressures causing inspiration
3. intrapulmonary negative pressures
4. extrathoracic positive pressures which support expiration.

The flow of air resulting from such pressure changes has to overcome a resistance due to the dimensions of the air passages[1] as well as an elastic resistance[2] The dimensional resistance to air flow is present throughout the airway but is most pronounced in the bronchioles. The elastic resistance is the sum of the broncho-pulmonary elasticity and the elasticity of the thoracic wall, the diaphragm, and the abdominal wall.

The conventional respirators now in use (tank, cuirass) are not suitable for examination of the reaction of patients to artificial ventilation, because the rate of air flow varies during inspiration. Only the so-called finger-ventilation (Fig. 5) is fit for experimental examination because here air is insufflated into the respiratory organs at a constant flow-rate throughout the inspiratory phase.

Experimental Technique

In finger-ventilation air is supplied from an oxygen cylinder provided with a reduction valve The air is led to one branch of a T-tube; the second branch is in airtight connection with the trachea through a cannula or tube, the third branch is open to the atmosphere

[1] Dayman (1951), Neergaard & Wirtz (1927), Rohrer (1925), Tiffeneau (1949)
[2] Christie (1934), Neergaard & Wirtz (1927), Rahn *et al* (1946), Tiffeneau (1949)

The open end of the tube is closed during inspiration by a finger, so as to allow the air from the cylinder to flow directly into the respiratory organs. During expiration the finger is removed. The

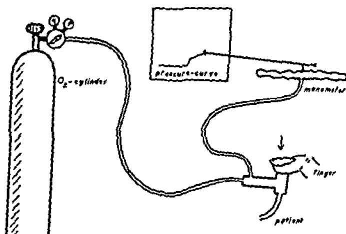


FIG. 5

variations of pressure are measured at the tube-connection and registered by a continuously recording manometer. The pressure curve is characteristic, a momentary rise sets in immediately when insufflation (inspiration) is started—the initial rise of pressure. Subsequently the curve rises in a straight line, and finally, at the start of the expiratory phase it falls sharply to atmospheric pressure (Fig 6).

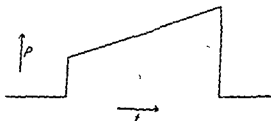


FIG. 6

In this and the following diagrams p=pressure; t=time

This pattern is used in all the following experiments. The three factors: inspiratory flow-rate, resistance to air-flow, and elastic resistance determine the configuration of the curve.

The pressure curve (Fig. 6) can be analysed by means of a lung model (Fig. 7 (A)) imitating conditions in patients with respiratory paralysis.

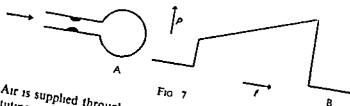


FIG 7

Air is supplied through a tube It has to pass a narrowing, constituting a resistance to air-flow, before it reaches an elastic, hollow body, e g., an elastic bag, which in the resting position is inflated without being distended Pressure curves recorded at the beginning of the tube in this lung model are identical to those registered in patients (Fig. 6)

A series of lung model experiments with this technique will now be discussed, air being supplied at a constant rate. First the effect on the curve exerted by the individual parts of the lung model are ested.

xamination of resistance to air-flow

If the air has to pass a narrowing of the tube (Fig 8) the pressure rve rises abruptly and remains constant during the insufflation, the end of which it drops sharply (Figs. 8 (B) and 9 (A)).



If the same volume passes the tube at half speed, the pressure will only go up by 50 per cent. (Poiseuille's law), and the passage through the tube takes twice as long (Fig. 9 (B)).

Likewise, if the flow-rate is doubled the rise in pressure will also be twice as high, *i.e.*, it takes only half the time for the air to pass the narrowing (Fig. 9 (C)).

The areas circumscribed by the curves are of identical size representing the volume of air passing the narrowing.

The elastic resistance

In this experiment (Fig. 10) the air enters directly into the elastic bag without resistance to air-flow in the air passages.

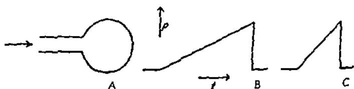


Fig. 10

The curve goes up in a straight line with an inclination dependent on the elasticity of the bag (lungs) and the rate of insufflation (Fig 10 (B)). The curve being rectilinear and the flow-rate being constant, the pressure of insufflation will at any point be proportional to the air-volume delivered, and the maximal pressure will be proportional to the total volume of air.

Ventilation Experiments with the Lung Model as a Whole

The following experiments illustrate theoretically some of the practical problems encountered when working with respirators—either of the conventional or of the intratracheal positive pressure type.

The relation between rate of air-flow, insufflation (inspiration) time, insufflation pressures and tidal volumes under different circumstances is examined in the lung model under conditions of constant resistance to air-flow and constant elastic resistance, as seen in a patient in a steady state.

CONSTANT TIDAL VOLUME IN RESPECT TO VARYING INSPIRATORY FLOW-RATES

The point of departure in this as in all the following experiments is tidal volume of 0 5 litre, achieved by an initial rise in pressure to 100 mm H_2O, and a maximal pressure of 200 mm H_2O (Fig 11 (A))

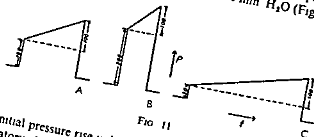


FIG 11

The initial pressure rise indicates the pressure which, throughout the inspiratory phase, overcomes the resistance to air-flow The maximal pressure of 200 mm. H_2O indicates that a further rise of 100 mm. H_2O is required in order to overcome the elastic resistance in the lung model, when 0 5 litre of air is delivered

If air be supplied at an insufflation rate twice as high (Fig 11 (B)) the same tidal volume will be delivered in half the time The initial pressure rise will be doubled, going up to 200 mm. H_2O When the tidal volume is unchanged (0 5 litre), the rise in pressure due to the elastic resistance also remains unchanged at 100 mm H_2O, and the maximal pressure rises to 300 mm H_2O

If the inspiratory flow-rate is only half of the original value the initial pressure rise will also be halved, but as the elastic resistance is unchanged (100 mm H_2O) the maximal pressure is 150 mm H_2O.

Decreasing insufflation rates are of course combined with decreasing initial pressures so that the maximal pressure needed for the delivery of one half litre of air to the bag (lungs) approaches the pressure required for overcoming the elastic resistance alone, in these experiments 100 mm H_2O

CONCLUSION

The flow-rate at which a certain tidal volume is delivered to a respiratory system determines the maximal pressure, but maximal pressure and flow-rate are not proportionally interrelated.

The Relation of Maximal Inspiratory Pressure to Tidal Volume in Respirators set at Constant Length of Inspiration

If the duration of inspiration is kept constant the tidal volume will prove to depend on the inspiratory pressure which again will depend on the inspiratory rate of air-flow.

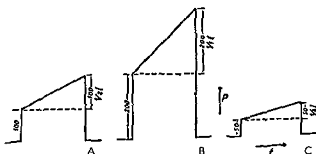


Fig 12

In this experiment (Fig. 12) the inspiration time is constant, and it is shown how variations in the inspiratory flow-rate affect the maximal pressure and the tidal volume.

As in former experiments the point of departure is a tidal volume of 0 5 litre, an initial rise in pressure of 100 mm. H_2O, and a maximal pressure of 200 mm. H_2O (Fig. 12 (A).

If the inspiratory flow-rate is doubled the initial pressure will rise to 200 mm H_2O. As the length of inspiration is kept constant this doubled flow-rate will deliver twice as much air and the tidal volume will be 1 litre. When the elastic resistance has been overcome the further rise in pressure will be twice as high as before, *i e.,* 200 mm. H_2O, and the maximal pressure will go up to 400 mm. H_2O (Fig. 12 (B)).

If the inspiratory flow-rate is halved (Fig 12 (C)) the initial rise in pressure will also be halved and only 50 per cent. of the original tidal volume will reach the patient The overcoming of the elastic resistance will only cause a 50 per cent. rise in pressure. The maximal pressure rise will be only half of the original.

Conclusion

In respirators set at a constant duration of inspiration, the tidal

VENTILATION IN PRESSURE-CONTROLLED RESPIRATORS SET AT A CONSTANT MAXIMAL PRESSURE IN RELATION TO DIFFERENT INSPIRATORY FLOW-RATES

Pressure-controlled respirators can be adjusted at certain maximal pressures When this pressure is achieved inspiration stops and expiration begins.

As in the former experiments the point of departure is a tidal volume of 0 5 litre obtained by an initial pressure rise of 100 mm H_2O and a maximal pressure of 200 mm H_2O, *i.e.*, the pressure to which the respirator is adjusted (Fig. 13 (A))

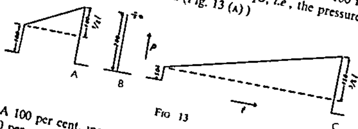


FIG 13

A 100 per cent. increase of the inspiratory flow-rate will cause a 100 per cent increase of the initial pressure rise to 200 mm. H_2O. Thus the maximal pressure is obtained immediately upon start of inspiration, which is interrupted and automatically followed by expiration. In this case no air (tidal volume) will be delivered to the bag (lungs)

If the inspiratory flow-rate is halved the initial pressure rise will only amount to 50 mm H_2O The rise in pressure now available for the overcoming of the elastic resistance is 150 mm. H_2O The resulting tidal volume will be $150/100 \times 0.5$ litre $= 0.75$ litre

If the flow-rate is extremely slow no initial rise of pressure occurs and the total pressure—200 mm H_2O is available for overcoming the elastic resistance It is theoretically possible in such cases to reach a tidal volume of one litre

CONCLUSION

With a pressure-controlled respirator working at a constant maximal pressure the tidal volume may vary between zero, when the inspiratory air-flow is high and a theoretical maximal value when the flow-rate is very slow.

RESPIRATORS: THEORETICAL ASPECTS

Artificial ventilation usually presents no special problems in patients with uncomplicated respiratory paralysis

Two complications, however, are frequently present and may give rise to special difficulties, *namely:*

1. physical obstruction, which prevents air from reaching the alveoli
2. leakage, which permits the escape of air intended for the patient

Principles of artificial ventilation

Tank respirators and intratracheal positive pressure respirators including the manual bag-ventilator differ in respect of ventilatory capacities. When complications occur—accumulation of secretions, atelectasis—the tidal volume delivered by the body respirator decreases, while in the case of intratracheal positive pressure ventilation (bag method) an unchanged tidal volume can be maintained provided there is no leakage.

In the following experiments with the lung model the first series imitates conditions pertaining to intratracheal positive pressure ventilation (bag method), *i.e.*, a volume cycled respirator, because irrespective of pressures a fixed tidal volume is delivered to the patient. The second series imitates the working conditions of the body respirators, *i.e.*, a pressure cycled respirator, because here the respiratory organs of the patient are submitted to certain pressure variations, which determines the tidal volume.

Volume cycled respirator

A volume cycled respirator offers the patient a constant air volume during each inspiration, the air being blown directly into the respiratory organs regardless of pressure—this, of course, presupposes an airtight system (Fig 14 (A)).

Pressure cycled respirators

In pressure cycled respirators—for example the tank respirator—inspiration is produced by submitting the respiratory organs of the patient to certain predetermined pressure variations.

An imaginary intratracheal positive pressure respirator with a

bellows, undergoing large variations of volume in respect of the desired tidal volume is actually a pressure cycled respirator.

If the volume variation of the bellows is fixed at 25 litres per cycle (Fig 14 (B)), 24·5 litres has to escape through the blow-off valve in

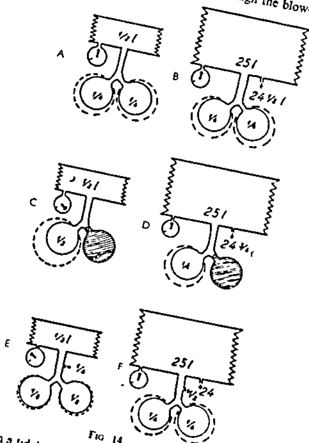


Fig 14

order to obtain a tidal volume of 0 5 litre, *i e*, the tidal volume used in all the previous experiments.

If total obstruction occurs between the respirator and the patient, 25 litres of air must pass the blow-off valve causing a slight increase (1/50) in inspiratory pressure.

CONCLUSION

Leakage in volume cycled respirators causes a fall in tidal volume and in inspiratory pressure.

OBSTRUCTION IN PRESSURE CYCLED RESPIRATORS (FIG 14 (D))

No air penetrates into the obstructed lung The free lung is ventilated at the same pressure as before, i.e , this lung receives the same tidal volume as under uncomplicated conditions, i e., the total tidal volume is halved.

CONCLUSION

In pressure cycled respirators obstruction causes a fall in tidal volume.

LEAKAGE IN PRESSURE CYCLED RESPIRATORS (FIG. 14 (F))

Leakage with escape of 0·5 litre of air in the pressure cycled respirator causes pressure variations similar to those encountered when no leakage is present, so the tidal volume remains 0 5 litre

CONCLUSION

In pressure cycled respirators the tidal volume remains unaffected by leakage.

CLASSIFICATION OF RESPIRATORS

The following is an attempt to classify the respirators actually in use (Lundia, Bang, Aga, Engstrom, tank, etc) according to the above description of the theoretical types

The **Lundia** respirator (Fig. 15 (A)) is a volume cycled respirator Air is supplied from a bellows with adjustable volume variations= tidal volume (*cf* Fig. 14 (A)).

Manual positive pressure ventilation is generally performed as the volume cycled type of ventilation

The **Engström** respirator (Fig 15 (B)) is also a volume cycled respirator. From a rubber bag a given volume of air is pressed down into the respiratory organs. During inspiration a pump creates a positive pressure in a chamber surrounding the bag The inflation pressure is adjustable by a blow-off valve.

In the **Gullberg** respirator (Fig. 15 (C)) air is supplied from a bellows with volume variations of 1·3 litre. Thus 0 8 litre of air must pass through a blow-off valve in order to obtain tidal volume of 0·5 litre. This respirator is of an intermediate type.

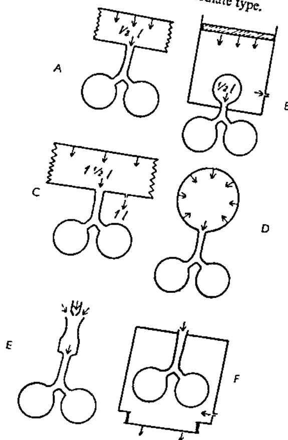


FIG 15

The **Bang** respirator (Fig 15 (D)) maintains a constant ventilation per time unit Air is supplied continuously to a rubber bag. Deflation of this bag forces air into the patient's lungs during inspiration. The respirator compensates satisfactorily for bronchial obstruction. In case of leakage the ventilation falls

The **Aga Pulmospirator** (Fig 15 (E)) is pressure controlled (*cf.* Fig 13) (not the same as pressure cycled). Air is delivered from an ejector

operated by compressed air or oxygen and sucking in ambient air. The tidal volume depends on the state of the patient, the inspiratory flow-rate, and the maximal inspiratory pressure

In cases with obstruction the ventilation falls; when leakage occurs the ventilation falls even if the tidal volume increases (*cf.* Fig 13 (c)). (Leakage causes a slow insufflation rate.)

Body Respirators (Fig. 15 (F)). In tank and cuirass respirators the respiratory organs are exposed to fixed pressure variations, so these respirators are of the pressure cycled type (*cf.* Fig. 14 (B)).

Routine Use of the Different Types of Respirators

Volume cycled respirators offer a number of advantages in the treatment of respiratory paralysis when obstruction of the airway can be anticipated, *i.e.*, in the acute stage.

1. Partial obstruction causes no fall in tidal volume, and if there is no leakage the patient is still, within certain limits, satisfactorily ventilated

2. Obstruction is disclosed at an early stage by a rise of inspiratory pressure.

When using this system a good fit of the endotracheal tube is important.

In **pressure cycled respirators** it is not possible to detect obstruction before the appearance of clinical signs of hypoventilation.

In the post-acute stage of respiratory insufficiency certain respirators have definite advantages In pressure-cycled respirators the question of a tight fit is only of slight importance, and cuirass respirators permit the removal of the cannula should spontaneous respiration not prove wholly satisfactory

Conclusion

The experiments and deliberations in this chapter are in accord with our practical experience during the polio epidemic in Copenhagen in 1952 and after Our results with tank and cuirass respirators in the acute stage were unsatisfactory, but results improved when manual positive pressure ventilation was introduced as a routine method. This probably was partly due to the abandonment of the pressure cycled respirators (tank, cuirass) in favour of the volume cycled manual bag ventilation.

CHAPTER VI

THE ACUTE STAGE: CLINICAL OBSERVATION

BY T. SØTTRUP

GENERAL

ALL patients admitted with life-threatening poliomyelitis were treated in single rooms with a personal nurse and frequent medical attention —a specially trained physician always being on duty in each department comprising about fifteen to twenty rooms. Actually the minutiae of treatment were discussed in each instance by a team comprising: epidemiologists, internists, laboratory experts, laryngologists, and anaesthetists.

During the observation period hourly measurements were made of the temperature, pulse rate, respiratory rate, and blood pressure. Several times during the day and night—in some cases even every two or three hours—the vital capacity was measured—with an ordinary gasometer or with a small pocket spirometer If no such measurements could be carried out e g, in very young children, a rough estimate was attempted. The patient's own respiration was closely watched: was it laboured, or associated with abnormal retractions—either epigastric during the inspiration, or supraclavicular—was it accompanied by asymmetrical movements of the chest, or the use of auxiliary respiratory muscles? The patient's coughing capacity was frequently examined For, if the cough becomes paralytic, it is most often a warning of incipient paralysis of the diaphragm and imminent secretory stagnation

If the respiratory or swallowing insufficiency progressed beyond quite mild degrees, the patient was a candidate for tracheotomy—a state in which at any time indication for immediate tracheotomy might arise Our indications will be mentioned in detail in the next chapter.

According to our experience, as long as the temperature was high, a risk of progression of paralysis had to be considered. The appearance of such signs as bilateral paralysis of the upper extremities, quadriplegia, cerebralia, etc., were so often followed or accom-

panied by progressive respiratory paralysis as to constitute definite signals of danger.

If necessary, determinations of the arterial oxygen saturation, the pH of the blood, and its content of absorbed carbon dioxide (pCO_2) and the CO_2 carried as bicarbonate (bicarbonate—alkali reserve) were made.

According to the course of events in individual cases, one or other of the following procedures might be indicated:

1. the cessation of the observation period,
2. institution of postural drainage (Figs. 16 and 17),
3. respirator treatment in a cuirass or a tank—or
4. the performance of a tracheotomy, usually in combination with artificial ventilation in the form of manual or mechanical positive pressure ventilation.

Patients who required no further observation because their respiratory or swallowing insufficiency improved considerably or subsided completely, could be transferred from the observation ward to an ordinary poliomyelitis ward.

Patients who did not need tracheotomy may be classified as follows:

1. Patients with pharyngeal paralysis alone. These were treated with postural drainage and stomach tube.
2. Patients with relatively slight respiratory paralysis. Pharyngeal paralysis was absent, but there was usually clear-cut spinal paralysis of a partial character. These patients were quite suitable for treatment in respirators of the cuirass or tank type as long as they remained dry. But, of course, they had to be kept under constant observation.
3. Patients with polioencephalitis. As the epidemic proceeded we were able to tide over an increasing proportion of such patients by conservative treatment in the form of postural drainage and stomach tube, together with frequent suction from the pharynx.

If, however, secretions began to accumulate in the air passages tracheotomy was indicated, and the same applied to patients who, on account of restlessness or other reason made conservative treatment impossible.

Patients requiring tracheotomy may also be grouped:

1. Patients treated operatively as an urgent procedure on admission.



FIG. 16
Improvisation of postural drainage.

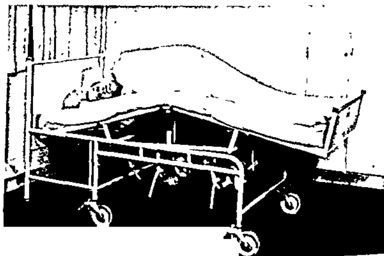


FIG 17
Postural drainage bed (C G. Engström).

2. Patients with polioencephalitis or pharyngeal paralysis with accumulation of secretions in the lower air passages, or in whom this complication continually threatened.

3. Many patients with severe paralysis of the respiratory muscles —often concurrent with polioencephalitis, pharyngeal paralysis or with cerebralia, *i.e.*, cases in which adequate alveolar ventilation could not be maintained by means of conventional respirators.

In most of these patients the ventilation was maintained for many weeks by means of manual positive pressure respiration with absorber system. Later, however, we went on increasingly to use—also in the acute stage—mechanical positive pressure respirators, especially the Engström respirator and the Gullberg attachment to the Kifa respirator.

Close observation and laboratory control round the clock was still required in these seriously ill patients who were threatened by many dangers.

COMPLICATIONS

The more important complications during the acute stage of poliomyelitis with respiratory or deglutitory insufficiency are as follows.

Infection of air passages

This risk is great, partly on account of the tracheotomy, partly because the coughing capacity and the ciliary function of the epithelium are abolished. Prophylactically and therapeutically therefore, we gave penicillin G or procaine penicillin and streptomycin for the first seven to ten days, then sometimes aureomycin or other antibiotic on the basis of sensitivity tests.

Efforts should be made to counteract the increased tendency to accumulation of secretions in the bronchial tree by frequent endotracheal suction—every two or three hours—with soft catheters and also by means of lung physiotherapy.

Crust formation in the air passages is constantly threatening. But it has proved possible to reduce this considerably by effective moistening of the inspired air. This point we consider of major importance.

Search for possible atelectasis should be made daily by auscultation and observation of the thoracic movements as well as daily bedside X-ray examination. Often it was possible to clear atelectasis by means of lung physiotherapy including postural drainage

Nevertheless, direct bronchoscopy through the tracheal stoma is frequently required.

Hypoventilation

This is always an imminent complication, partly because of secretory stagnation and atelectasis, partly because of incorrectly administered positive pressure ventilation. Distinction should be made between *hypoventilation with regard to oxygen and to carbon* dioxide, but most often poor oxygenation and deficient elimination of CO_2 are found simultaneously.

The chief symptoms of frank hypercapnia are: increased blood pressure, sweating, especially of the extremities—increased salivation, increased bronchial secretion, relative bradycardia, and mental haziness developing into coma.

The symptoms of hypoxia are restlessness, tachycardia, cyanosis, fluttering of alae nasi, and tachypnoea. The patient tries in vain to increase his alveolar ventilation, by using the cervical muscles or the muscles of the floor of the mouth. These patients are often wrongly diagnosed as being neurotic or euphoric.

The ultimate clinical picture of hypoventilation depends upon arterial oxygen and carbon dioxide levels. It is often very complex, therefore, and difficult to evaluate clinically.

In our cases we supplemented the clinical estimation by frequent measuring of the blood pressure, the expired volume of air per minute, and examination of the oxygen saturation, the pH, and the pCO_2 of the arterial blood (Astrup *et al.*, 1954).

Hyperventilation

We found that the person administering manual positive pressure ventilation very often tended to hyperventilate the patient because he was eager to do his best. But apart from the human element inherent in the manual bag ventilation method we feel that all mechanical methods of positive intratracheal pressure ventilation *tend towards a state of hyperventilation*.

Another contributory factor appears to be that the patient very soon becomes accustomed to an alveolar ventilation greater than normal, resulting in a lower pCO_2, and, presumably an increased sensitivity of the respiratory centre, which causes the patient to *demand more air*.

If the patient is not too extensively paralysed, tetany with spasms may appear in response to pronounced hyperventilation.

Shock

This complication was very frequent in 1952 though only in the acute stage. Besides the circulatory effect of manual positive pressure ventilation, the pre-disposing factors of circulatory shock appear to be: hypoxia and hypercapnia, severe poliomyelitic infection in the brain stem (vegetative centres?), and, possibly, damage to the myocardium

Soon after the onset of the epidemic we realised that vascular shock in these patients need not be accompanied by a low blood pressure On the contrary, in some cases the state of shock was even accompanied by a relatively high blood pressure This, we think, is due to concomitant hypoventilation with hypercapnia and hypoxia, masking the early signs of shock by producing hypertension If ventilation is increased this type of hypertension will disappear In other cases a state of shock may be masked by the simultaneous presence of hypertension of central—true poliomyelitic—origin In such cases correction of the ventilatory state does not produce a decrease in the blood pressure.

Oedema of the lungs

Many causes may contribute to this condition faulty positive pressure ventilation, blockage of a bronchus or sudden abolition of a bronchial plug, hypoxia, severe virus infection in the brain stem or the myocardium, and sometimes overdosage of fluids It would seem that electrolyte overdosage (NaCl) may be injurious On this account we tried to keep the Cl^- content of the urine at a level of 0 1 to 0 2 per cent.

Azotaemia

A moderate increase in nonprotein nitrogen (NPN) is almost the rule in patients with life-threatening poliomyelitis—partly on account of muscular disintegration and inanition, partly also on account of anoxaemic impairment of the kidney function in the shock period This condition may lead to true uraemia with anuria which has proved intractable

The blood should be examined daily for nonprotein nitrogen, and the output and specific gravity of the urine measured In addition,

the haemoglobin percentage and the blood electrolytes should be frequently determined in order to detect haemoconcentration.

Hyperpyrexia

This is a frequent feature in the acute stage, often associated with a severe condition of circulatory shock. Most commonly it is attributable to irritation of centres in the thalamus although it may be due to bacterial infection in the lungs or elsewhere.

Ordinary antipyretics are ineffective. Mechanical cooling of the patient—by uncovering and the employment of wet sheets is better.

Paralytic ileus and gastric atony

These conditions are frequent in the beginning of the disease, due to poliomyelitic lesions of vegetative centres and ganglia, or to electrolyte disturbances.

As this complication very easily hampers diaphragmatic movement, its treatment and prophylaxis are of importance. The risk of its development appears to be greatest within twenty-four hours after the performance of tracheotomy. Consequently no nourishment should be given through the stomach tube during this period.

When gastro-intestinal retention is manifest, the stomach should be emptied—if necessary, by permanent suction—and treatment instituted according to the usual principles with injections of prostigmine, irrigation enemata, correction of electrolyte disturbances, etc.

Paralysis of the bladder

This is very frequent in the acute stage, but it always subsides within eight to fourteen days. It is treated with carbacholine and catheterisation, an in-dwelling catheter may be necessary. Infection of the urinary passages will often result.

In conclusion, mention must be made of some less frequent complications which played a minor rôle in the present series.

Decubitus ulcers, especially in the occipital region and on the buttocks and on the iliac crests during treatment in cuirass respirators.

Phlebitis of superficial veins, usually of a chemical nature after infusion through in-dwelling polythene catheters, as well as deep thrombophlebitis, though this very rarely occurred

Haemorrhagic diathesis, mostly shown by decreased capillary resistance.

Ordinary hypochromic anaemia of infectious origin, often on account of protracted urinary infection, bronchial infection, or decubitus ulcers.

Purulent conjunctivitis and lagophthalmic keratitis in patients with severe facial paralysis.

The subject of the complications encountered cannot be completed without including pregnancy. Perhaps it aggravates prognosis *quoad vitam*. At any rate it evidently impairs regression of the respiratory paralysis Therefore, if the patient so wished, we terminated the pregnancy—in two cases by performing Caesarean section (one child is living). Two patients—likewise according to their own wish—preferred to let pregnancy go on to term and gave birth to live children by natural delivery in spite of the mother's respiratory insufficiency.

CHAPTER VII

THE ACUTE STAGE: TRACHEOTOMY AND BRONCHOSCOPY

By J Falbe-Hansen, W Dam, Bjorn Ibsen, *Steen Johnsen and J Schou*

Tracheotomy was first introduced *in the treatment of* bulbar poliomyelitis by Wilson (1932), but in the following decade it was performed only to a small extent. Through his report in 1943 Galloway (1943) aroused renewed interest in this form of *surgical intervention*, and in the following years it was employed in a greatly increasing number of patients with life-threatening poliomyelitis

In the Blegdam Hospital tracheotomy was performed for the first time in the 1948 epidemic, but the results were discouraging, because at that time we had not mastered all the supplementary therapeutic measures which today have entirely altered the prognosis.

INDICATIONS FOR TRACHEOTOMY

1. Urgent indications

On admission a great number of our patients were markedly hypoxic, cyanotic, restless or comatose with only slight or almost no respiration, the air passages being more or less obstructed by secretions from the pharynx or stomach. In these cases immediate tracheotomy with careful suction of the bronchial tree was life-saving and had to be carried out before the extent of the paralysis could be estimated

2. Clear-cut bulbar poliomyelitis

This term covers paralysis of the vagus, sometimes combined with paralysis of the glossopharyngeal, accessory and hypoglossal nerves In this group of cases tracheotomy is indicated:

a. in the presence of paralysis of swallowing and coughing when the air passages cannot be kept free in spite of suction and postural drainage (sometimes combined with tracheo-bronchial toilet through a nasal catheter)

b. *when areas of atelectasis in the lungs are already present in* combination with pharyngeal paralysis

c. in bilateral laryngeal abductor paralysis and

d in the presence of Sjöberg's angular syndrome (Sjöberg, 1950) with paralysis of the infralaryngeal cervical muscles and elevation of the larynx, so that the *introitus laryngis* is closed against the base of the tongue

3. Bulbospinal poliomyelitis

This condition, accompanied by pronounced respiratory paralysis, is mentioned in connection with one of the indications under point 2.

4. Polio-encephalitis

Tracheotomy may be required in this group of cases for the following reasons·

a. The patient may be in a state of coma and have respiratory failure.

b There may be restlessness preventing postural drainage and suction.

c. There may be vomiting in patients in whom postural drainage is impossible on account of restlessness.

5. Respiratory paralysis

We refer here particularly to cases which require respirator assistance when no special apparatus is available, except the apparatus for manual or mechanical positive pressure ventilation At the sudden outbreak of a very extensive epidemic with numerous cases of respiratory paralysis it may be necessary to perform tracheotomy for this reason. This had to be done several times in 1952.

TRACHEOTOMY

Tracheotomy for cases of poliomyelitis differs in several respects from the usual operation. The following practical points are emphasized because they are the results of our own experiences

It should be stressed that it will nearly always be necessary to perform the operation *in the ward*. This can be done without great difficulty if the patient is in a single room during the pre-operative observation period, as should be the rule. The apparatus for anaesthesia, surgical instruments, suction apparatus, oxygen cylinder, etc, are placed around the bed, so that it is unnecessary to move

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tracheal rings, an oval fenestra being excised. With the intratracheal tube *in situ*, this excision can be performed without difficulty. When haemostasis has been established, the peroral tube is withdrawn so that its tip is situated just proximally to the fenestra. At this point it is important that the peroral tube should not be retracted further, so as not to exclude rapid continuation of ventilation through the peroral catheter if introduction of the cuff-tube into the trachea should give rise to hypoxia When the widest possible cuff-tube has been inserted through the fenestra the oral tube is removed completely

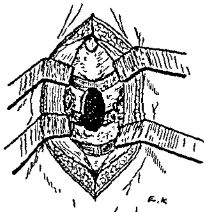


FIG. 18
Tracheal fenestra before introduction of the cuff-tube

and the cuff is inflated to such an extent that it fits the tracheal wall At this juncture the cyclopropane supply is shut off, and while the wound is closed by two or three sutures, the patient is given fifty per cent oxygen, so that he is awake at the end of the operation.

Before fixation of the cuff-tube it is important to make sure that its tip does not project beyond the carina for otherwise it will enter the right main bronchus. With proper placing of the tube the two halves of the chest should move symmetrically under positive pressure ventilation. The tube is held in place by means of a clamp that is kept from sliding by fixation with adhesive tape (Figs. 19 and 20), or by using a rubber tube with a shield

In our experience, it is highly important that the operation is performed under oral intubation, that a fenestra is excised, and

hypoxic or anxious patients to the operating room. Sudden obstruction of the air passages during transport of the patient is thus avoided.

General anaesthesia is employed, as pre-operative oral intubation under local anaesthesia is seldom practicable in these patients No premedication should be given, as opiates or barbiturates are contra-indicated on account of their depressant effect on respiration. Drugs belonging to the belladonna group should be avoided so as not to render the secretions in the respiratory passages too tenacious and difficult to remove. The type of anaesthesia desirable is one with a brief and not too unpleasant initial phase. This can be obtained with cyclopropane-oxygen anaesthesia.

Technique of anaesthesia

It is most desirable to employ a semi-closed system in which a Waters absorber is inserted for absorption of carbon dioxide. Anaesthesia is induced by letting the patient inhale pure oxygen with a flow of four to five litres per minute. When the anaesthetist is satisfied that there is no leakage in the system, each inspiration is increased by pressure on the breathing bag at the beginning of the inspiratory phase in order to increase the oxygen intake and carbon dioxide elimination.

[illegible]

to ventilate. At first the anaesthetist presses the breathing bag at each inspiration (assisted respiration), but as soon as practicable, he takes complete charge of the respiration (controlled respiration). After a couple of minutes of hyperventilation with the cyclopropane-oxygen mixture, the patient will as a rule relax to such an extent that there is ample time for oral intubation and suction of secretions accumulated in the bronchial tree. During the surgical intervention, which may begin immediately after the intubation, the patient is given a mixture of cyclopropane and oxygen, most often in the proportion of about 200–300 ml. of cyclopropane to 1,000 ml of oxygen.

Operative technique

Through a vertical incision of about four to five centimetres, a high tracheotomy is performed, corresponding to the first and second

that an inflatable cuff-tube is employed—not an ordinary tracheal cannula

A. *Pre-operative intubation offers the following advantages:*

1 By positive pressure ventilation through the peroral tube ventilation can be controlled during the operation.
2 In case of threatening obstruction of the air passages tracheobronchial toilet can be carried out without delay.
3. The operative intervention can be carried through without haste in a surgically satisfactory manner.
4. Bleeding from the operation field before complete haemostasis is established cannot invade the trachea and bronchi. This point is particularly important post-operatively in patients with feeble coughing power.

B It is preferable to cut out a fenestra and not merely make a simple incision into the trachea for the following reasons

1. During the post-operative period the necessity to perform bronchoscopy or to change the tube quickly may become a matter of urgency. The situation here encountered may be extraordinarily dangerous, and bronchoscopy as well as change of tubes can be carried through most rapidly if a fenestra has been made

2. The pressure of the tube on the circumference of a fenestra is less than on a linear incision, thus diminishing the risk of necrosis and subsequent granulation formation.

C. The use of a tracheal tube with an inflatable cuff secures an effective closure of the trachea so that secretions from above cannot reach the lower air passages

Finally, it is to be emphasized that the transverse diameter of the fenestra should not exceed one-third of the diameter of the trachea Otherwise damage to the tracheal rings will lead to collapse and stenosis of the trachea when the tube is removed

THE POST-OPERATIVE PERIOD

In the post-operative period there is usually a considerable amount of tracheobronchial secretion, especially during the first couple of weeks, in a lesser degree during the subsequent period when the

FIG 19
Fixation of cuff-tube by means of Kjørboe's clamp



FIG 20
Patient with cuff-tube and duodenal tube

in the lower parts of the bronchial tree and is an indication for immediate bronchoscopic suction.

Bronchoscopy

This should be performed through the tracheal stoma and without anaesthesia It must be very brief, and oxygen should always be supplied during the procedure. In spite of this, however, the patient often becomes cyanotic and rather exhausted before the operation can be concluded. By squeezing of the thorax and tapôtement done by the chest physiotherapist, the bronchial secretions can be brought up into the larger bronchi and aspirated directly through the bronchoscope. In the rare cases of incrustations occurring in the bronchial tree, these will have to be removed by suction, or by means of a foreign body forceps.

In the post-operative period the cuff-tube is replaced by a silver tube when swallowing has been restored. The risk of stomach contents or pharyngeal secretions spilling over into the air passages is now past so that the close-fitting cuff-tube is no longer necessary The positive pressure ventilation can readily be maintained through the silver tube, if it is large enough to fill the lumen of the trachea.

Tracheotomy and Bronchoscopy during the Poliomyelitis Epidemic in 1952-53

From August 30 1952 to April 1 1953 tracheotomy was performed on 268 patients. The sex and age distribution is shown in Table IX.

TABLE IX

SEX AND AGE DISTRIBUTION OF 268 TRACHEOTOMIZED PATIENTS

	Under 15 years	15 years or more	Total
Males	82	71	153
Females	55	60	115
Total .	137	131	268

Tracheotomy was performed in 12 per cent of the 2,241 cases admitted to the Blegdam Hospital. This high frequency of tracheotomy was partly due to the circumstance that an adequate number

rubber tube is replaced by a silver cannula. In the first place, both types of tube act as a foreign body irritating the tracheal mucosa. Furthermore, the air passages often become the site of a bacterial infection resistant to antibiotic treatment (e.g. Staphylococcus, Esch. coli or Proteus).

In the post-operative period it is very important to try to prevent stagnation of secretions in the cuffed tube and air passages. Sooner or later the inner surface of the cuffed tube becomes coated with a layer of tenacious secretion obstructing the lumen, so that the tube may need to be changed at frequent intervals. If this is not discovered in time the situation may become perilous. The patient becomes restless, sweating is observed, with slight cyanosis. If expeditious intervention does not take place he soon becomes deeply cyanotic and unconscious. In such cases the tube has to be changed very quickly. It may also be necessary to change the tube if it becomes rotated or displaced during the manipulation connected with positive pressure ventilation, or if the cuff of the tube is leaking.

Thick incrustations in the tube are rare, but efforts should be made to remove the layer of secretions deposited on the wall. This has been attempted by instillation of various substances claimed to dissolve mucopurulent secretions. For this purpose, five per cent. sodium bicarbonate and 1 per cent sodium lauryl sulphate as well as tyrothricine 0 025 per cent were employed without however any definitely demonstrable effect upon the amount or character of the deposits.

In order to remove secretions from the air passages, tracheobronchial cleaning through the tube must be carried out frequently. This is done by suction through a Tiemann catheter In some cases suction has to be performed several times an hour, in others only a few times a day The particular shape of the Tiemann catheter makes it applicable to both main bronchi. The catheters are sterilized once a day and are kept ready for use in a 0 1 per cent. solution of alcyl-dimethyl-benzyl-ammonium-chloride.

Stagnation of secretions in the smaller bronchial branches may give rise to atelectasis, and if the clinical and roentgenological signs do not disappear following vigorous tracheobronchial suction in combination with chest physiotherapy, bronchoscopy is indicated In some cases, in the post-operative period, a state of hypoxia may appear suddenly in spite of the tube being kept freely patent. Generally, this complication is due to accumulation of secretions

CHAPTER VIII

THE ACUTE STAGE: ARTIFICIAL VENTILATION

BY H C A LASSEN

BODY AND CUIRASS RESPIRATORS

No mechanical respirator can produce physiological respiration, either in respect of intrathoracic pressure curves or in respect of circulatory effect Most respirators now in use are far from ideal, but recent studies, mainly conducted in the United States of America of the ventilatory and circulatory characteristics of the different types have done much to increase our understanding of the underlying problems and have led to rational improvements.[1] As these are quite recent nearly all body respirators now in use are old-fashioned and are at least theoretically unable to supply optimal conditions However they seem in practice to be quite effective in many cases, and produce adequate ventilation with no noticeable harmful effect on the circulation This, at least, is true in patients who have passed the acute phase of respiratory insufficiency and in chronic cases, who seem to be able to adapt the circulation to unphysiological pressure conditions in the thorax In the acute, *wet* patient with circulatory instability or vasomotor shock and reduced cardiac output such an adaptation with restoration of a normal venous gradient does not seem possible (Carr and Essex, 1946, Whittenberger and Maloney, 1952), and this is probably a contributory reason for the frequent failure of the conventional respirators in the acute stage The main reason is, of course, that the machine cannot produce adequate ventilation when the bronchi and lungs are full of secretions.

A mechanical respirator must first of all be capable of offering the patient an adequate amount of air or oxygen—six to ten litres per minute. The intrapulmonary pressure curve should be of the type which causes least possible resistance to the venous return to the right heart, in order to avoid decreasing cardiac output and

[1] Bower *et al* (1950), Conference on Respiratory Problems in Poliomyelitis (1950), Whittenberger & Sarnoff (1950), Whittenberger & Ferris (1952), Whittenberger & Maloney (1952)

of mechanical respirators was not available during the epidemic. It should be kept in mind, however, that the decisive indication for tracheotomy is stagnation of secretions in the air passages in spite of adequate postural drainage, chest physiotherapy and suction. It was characteristic of the 1952 epidemic that it included an overwhelming number of *wet* cases which could not be managed with conservative methods.

From the case records as of January 1, 1956, the following data emerge:

a. Of the 268 patients submitted to tracheotomy, 115 died and 153 survived. The cannula has been removed from 133 of the survivors.

b. In no instance could the tracheotomy be considered a contributory cause of death.

c. Of immediate operative complications there was one instance of oesophageal injury in a child of one year, which healed within two weeks. Permanent sequelae did not occur.

d. There was no instance of post-operative pleural injury with pneumothorax or mediastinal emphysema and only in one case did an insignificant subcutaneous emphysema appear

e. Post-operative haemorrhage appeared in 14 patients—presumably because bulbar poliomyelitis is often accompanied by lowered capillary resistance. In most cases it stopped after tamponade with iodoform gauze.

f. Among the 268 tracheotomized patients, 112 were submitted to bronchoscopy, altogether 297 times—in 49 patients only once, in 26 twice and in 37 patients three or more times.

g. Among 153 surviving patients, 126 had clinically or roentgenologically demonstrable atelactasis at least once during the post-operative course.

The number of patients submitted to bronchoscopy more than once was relatively small in view of the frequency of atelectasis. Because of the risk of hypoxia and carbon dioxide retention we always hesitated to intervene in this way, and it was never done without first trying to clear up the atelectasis by postural drainage and suction combined with lung physiotherapy.

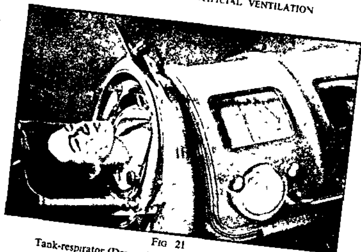


FIG 21
Tank-respirator (Draeger) showing neck-closure permitting tracheotomy

FIG 22
Tank-respirator (Draeger) with dome attached

shock.[1] Finally the respirator should be so constructed mechanically *that it is simple to* operate and can keep on going for weeks or months with a minimum of attention from the nursing staff.

In order to fulfil the basic ventilatory and circulatory demands the pressure curve delivered by a respirator should not be a half wave sinus curve, in which inspiration and expiration are of equal length *and the minimum intrathoracic* pressure never lower than the ambient pressure (Bower *et al.*, 1950) Sinus wave curves are produced in all conventional crank-actuated tank or cuirass respirators and in most machines used for intratracheal positive pressure ventilation.

*The inspiratory peak should be rather high and sharp, correspond*ing to a maximal pressure of twenty to thirty centimetres of water. It should be high enough to deliver an adequate volume of tidal air but not so steep that the pressure is inconvenient for the patient. The inspiratory phase should not cover more than one third of the whole *respiratory cycle and should end with a sharp expiratory* release, thus lowering the pressure to ambient (usually atmospheric) pressure The curve may indeed fall slightly below the base line to which it returns during the expiratory pause—a phase of the cycle which must always be respected. When positive intra-tank pressure is used, the inspiratory peak pressure may be reduced. An adequate tidal volume may still be secured in spite of decreasing mean intrathoracic pressure during the respiratory cycle. The lower this mean pressure can be maintained, *the less is the depressant effect on the venous* return to the right heart, on the cardiac output and on the blood pressure.[2]

TANK RESPIRATORS

In most tank respirators rhythmic negative intra-tank pressures make the chest expand with a resulting inspiration Expiration is passive, *the pressure returning to zero, i.e., atmospheric* pressure. In the most up-to-date tank respirators it is possible to assist expiration actively by applying positive intra-tank pressures

Because inspiration is actuated by negative intra-tank pressures one can easily fail to realize that the body respirator works as a

[illegible] (1953),

[illegible] 53);

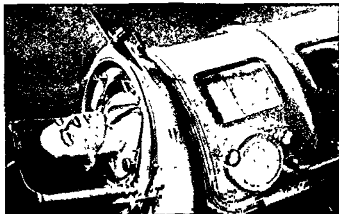


FIG 21

Tank-respirator (Draeger) showing neck-closure permitting tracheotomy

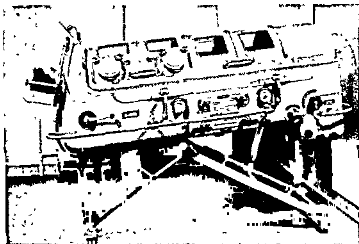


FIG 22

Tank-respirator (Draeger) with dome attached.

positive pressure breathing machine just as machines designed for intra-tracheal positive pressure ventilation. This is due to the fact that when a vacuum appears to perform work—as in the tank respirator—the work is in reality done by the relatively positive reference pressure, *i.e.*, atmospheric pressure. It is simply a question of base lines. In machines producing intratracheal positive pressure ventilation, the base line is atmospheric pressure, 760 mm -Hg., but in a body respirator working at a negative inspiratory pressure of—20 mm.-Hg. the base line is 740 mm.-Hg. In cuirass respirators, especially those not encircling the body, conditions are more complicated, yet these too are in this sense mainly positive pressure machines

If the airway is unobstructed and the tank does not leak, most tank respirators will produce adequate ventilation when properly handled —and they are very easy to handle. This fact, combined with their great reliability, is their principle advantage. Modern tank respirators, such as the one developed by Bennett (Bower *et al*, 1950), and by Drinker, Emerson, Draeger (Figs. 21 and 22) and others, are so constructed that intermittent positive pressure ventilation may be administered by enclosing the head in an airtight dome, so that the tank can be opened for parenteral injections and for nursing care. By the use of a specially designed rubber collar it is possible to treat patients in these tanks even after tracheotomy. Further by synchronizing a small cam-actuated bellows to the movements of the tank it is now possible to give intra-tracheal positive pressure ventilation to a patient in a tank. This is said to be a great advantage in acute cases, and probably is, especially if suction is applied during the expiratory phase.

ADVANTAGES AND DISADVANTAGES

The disadvantages of body respirators are obvious. First of all their psychological effect must be considered The patient is encased in a metal box—the dreaded iron lung—shut off from the outer world. Even if he has no peripheral paralysis, he cannot move, and if paralysed, his extremities cannot be placed so as to prevent contractures. Nursing and medical care is difficult, and physical treatment of peripheral paralysis, which is nearly always present, must be abandoned If the patient has hyperpyrexia or the outside temperature is high, he cannot be cooled down. Change of position, in order to avoid congestion or atelectasis of the lungs, or the carrying out

of lung physiotherapy, is either impossible, or must be greatly limited in extent. Only the most modern tank respirators allow of effective tilting and effective postural drainage. Finally the price of the modern body respirator is high (approx £1,500)

During the Copenhagen epidemic in 1952, forty-two patients with respiratory failure were first put into a tank or cuirass respirator

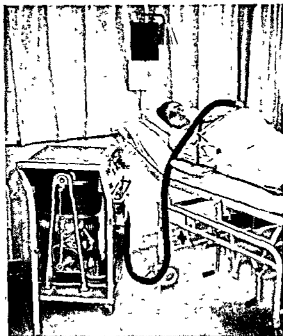


Fig 23
Kifa respirator The machine

because we hoped that they might be tided over in this way In thirty of these cases we had to resort to tracheotomy and manual positive pressure breathing—bag ventilation—and only twelve patients could be continuously ventilated in tank or cuirass respirators till spontaneous respiration returned. This, of course, was due to the fact that only a few patients were really well-suited for treatment in a tank. As a general rule, the tank respirator is only rarely effective in patients with bulbar poliomyelitis. The ideal case

for this treatment is the patient with a pure spinal respiratory insufficiency without bulbar involvement, *i.e.*, without accumulation of secretions in the airway—the patient who remains *dry*. In certain epidemics this type appears to be quite common. No doubt our results with tank respirators would have been better, first, if they had been used prophylactically in the incipient phase of respiratory



FIG 24
Kifa respirator. The cuirass.

failure, second, if we had not had such a large number of patients who had gone through hypoventilatory episodes before admission, and third, if a sufficient number of the most modern tank respirators had been at our disposal.

In cuirass respirators negative pressure is produced rhythmically inside a light metal or plastic shell, thus creating inspiration. By releasing the negative pressure, expiration follows passively through

the elastic recoil of the thorax or it may be assisted by alternately low positive pressures. The most commonly used types of cuirass respirators are Swedish or American—Sahlin, Kifa (Figs 23 and 24), Monaghan and Huxley. They are usually applied to the anterior surface of the body from the sternal notch down to the anterior spine of the ilium. As the thoracic cage is rather stiff, these respirators probably exert most of their effect through sucking out the anterior abdominal wall during the negative intra-shell phase, thus moving the diaphragm downwards (Plum and Lukas, 1951). Often it is not easy to make them sufficiently airtight to keep up adequate negative pressures In the Kifa the shell is so pliable that it is easy to adapt it to the body of the patient. Its great advantage is the inflatable rubber tube attached to the edge which, by suction, seals off the shell (Fig 24) The Kifa does not require much experience to handle Furthermore, the machine is remarkably reliable The patient may be in a semi-reclining position or may even sit up—an obvious advantage. Nursing and general care of the patient in the Kifa is easy, and patients do not seem to be afraid of these machines *Postural drainage in the supine position is possible*

Yet cuirass respirators have disadvantages which limit their use considerably. Thus in patients with greatly reduced respiratory capacity they often do not produce adequate ventilation, and they are, just as the body respirators—and for the same reasons—only rarely effective in *wet* cases. Their domain is the *dry* case with spinal respiratory insufficiency and perhaps especially when some spontaneous respiration is retained Cuirass respirators are particularly useful in the weaning period and during the chronic stage

Their cost is about £700.

INTRA-TRACHEAL POSITIVE PRESSURE VENTILATION

This has hitherto been used only infrequently in the treatment of poliomyelitis with respiratory insufficiency and for two reasons the procedure was thought to be unphysiological for prolonged use, and there was some, perhaps natural, reluctance to abandon the idea of the iron lung as the best means of ventilating patients with severe respiratory failure.

With us, in 1952, manual bag ventilation was introduced as an emergency measure, because of the catastrophic situation which

arose when only a few mechanical respirators were available. Tracheotomy and positive pressure ventilation were in such circumstances the only means of treating the great number of patients with bulbar and respiratory poliomyelitis. Time has shown that intratracheal positive pressure ventilation—manual or mechanical—can be kept up continuously and effectively for at least three years. Several workers (Motley *et al.*, 1948; Whittenberger and Ferris, 1952), have tested the mechanical features of different types of positive breathing machines. None of these has any appreciable depressant effect upon the circulation in normal individuals but the slight effect observed is proportional to the height of the mean mask pressure. Machines of the suck-and-blow type do not seem to produce adverse effects on the circulation, even in patients in deep coma when used for short periods of time. From other reports,[1] however, it would appear that when there is instability of the circulation, intermittent positive pressure breathing regularly produces a decreased cardiac output, and this defect increases the higher the mean pressure during the respiratory cycle. On theoretical grounds this appears quite reasonable, and for the same reasons suction during expiration is probably valuable in improving venous return.

METHODS OF ADMINISTERING INTERMITTENT POSITIVE PRESSURE VENTILATION

Manual bag ventilation

In Fig. 25 are shown schematically the various parts of the simple equipment used by us in about 300 patients subjected to manual bag ventilation (Lassen, 1953).

The upper part of the cuff-tube has a side branch connected with a metal container packed with granulated soda lime (Waters' canister) from which a rubber tube leads to a cylinder containing a mixture of compressed oxygen and nitrogen—most often we used half and half—or ordinary air. A rubber bag is attached to one end of the canister, and a valve at the other end permits regulation of the pressure in the system

As will be seen from Fig. 25, this is a semi-closed to-and-fro system similar to the one used in modern machines for general anaesthesia,

[1] Carr & Essex (1946), Maloney & Whittenberger (1951); Maloney *et al.* (1953)

where carbon dioxide is effectively removed and an adequate supply of oxygen secured when the flow-meter registers five to ten litres per minute. The bag is compressed from sixteen to thirty times per minute according to the patient's condition and age. The amount of oxygen mixture that should be given at each compression of the bag depends on the thoracic excursions and the general condition of the patient. The insufflation pressure must be short, and the bag must be

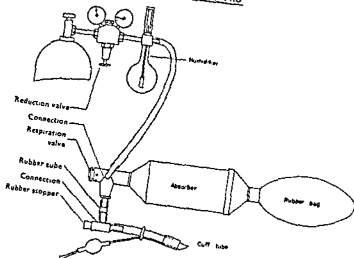


Fig 25
Manual bag ventilation shown schematically

released completely during expiration. This is very important for reasons already explained. At all times the bag should only be partly full of gas (Fig. 26). This can be regulated through the flow-meter and the valve at the top of the canister. We have several times measured the insufflation pressure when bag ventilation was administered correctly, and found it to amount to twenty to thirty centimetres of water. But the insufflation phase must be short.

Bag ventilation is especially well-suited for emergency treatment of patients where modern equipment for mechanical respiration is

FIG. 26
Bag ventilation with absorber.

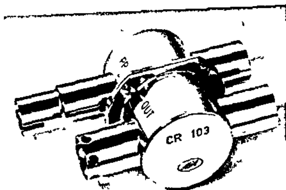


FIG 27
Non-return respiration valve.

not available and particularly before and during transportation by car or by plane to a treatment centre. It has the great advantage that it is independent of electric power.

The method has in addition great psychological advantages. The patient is not encased as in the notorious iron lung, with its collar either too tight or too loose to maintain the necessary intra-tank pressures and there is no danger of friction sores, which are not uncommon when the cuirass respirator is used. All the members of the staff and the many visiting colleagues were greatly impressed by the appearance of our patients receiving bag ventilation, by their calm, their apparent confidence, and total lack of apprehension.

The method has, however, certain obvious disadvantages:

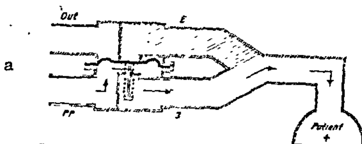
1. Particles of soda lime may be carried down into the bronchi and alveoli.
2. The assistance of well-trained personnel all round the clock is essential and costly. So far as the latter point is concerned, we were fortunate in being able to use medical students working in relays.

As to the first point, provided the best available preparation of soda lime is used, and the canister is packed carefully and thoroughly aired before being used, the danger that particles may be carried down into the lungs seems to be more theoretical than practical. Nevertheless, the desirability of completely avoiding the use of absorbers is obvious, and consequently we have experimented with different kinds of valves which separate the in-going and out-going flow of air, and at the same time secure atmospheric pressure in the lungs during the major part of the respiratory cycle, thereby hindering the venous return to the heart as little as possible.

Figs 27, 28 and 29 show a valve which we have now used for about two years and which has made absorbers unnecessary. Another method is simply to run a high flow. If the flow is fifteen to twenty litres per minute the absorber is not needed, but adequate humidification is particularly important to obviate incrustation of the mucous membrane of the trachea.

From the very early stages of the 1952 epidemic attempts were made to replace the bag ventilation method by mechanical appliances. Some such methods did already exist and several "mechanical students" have since been developed and used for long periods of time.

a



b



c



FIG 28

Function of Rattenborg non-return respiratory valve

a positive-pressure inspiration b=spontaneous inspiration c expiration.

PP—positive pressure E expiration. I inspiration.

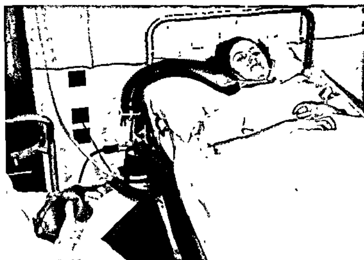


FIG 29

Manual bag-ventilation with electric humidifier and non-return respiration valve (see Fig 28)

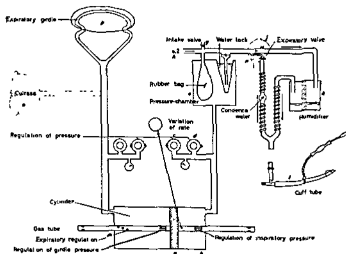


FIG 30

Schematic diagram of the Engström respirator

The Engström Respirator (Engström, 1954)

This is a flow-sensitive respirator producing a known minute volume designed for intratracheal intermittent positive-pressure breathing. It can be used with a mask, but is more effective if the patient has a tracheotomy. It is rather complicated (Figs. 30 and 31) and requires thorough understanding of its mechanical and ventilatory properties. It is, however, a very reliable and robust machine.



FIG. 31
The Engström respirator.

Its water-lock indicates immediately—by bubbling over of the water—when the pressure in the airway is increasing, for instance because of accumulation of secretions. We have used it on a number of acute, *wet* patients with satisfactory results and as a whole the Engstrom machine in our hands has proved more effective than tank respirators in the acute stage The length of the inspiration phase is half the length of the expiration phase; but this ratio can easily be changed The positive pressure comes abruptly down to ambient pressure, when the fixed volume of tidal air has been delivered In our opinion this respirator should have a thorough trial in acute patients In the

newest model expiration is assisted by suction. Manufacturers: *Mivab*, Stockholm, Sweden. The price is approximately £1000

The Gullberg Apparatus

The intratracheal positive pressure apparatus designed by Gullberg and attached to the Kifa cuirass respirator (Fig. 32) has been con-



Fig. 32
The Gullberg-Kifa respirator

structed essentially on the same lines as the Bennet positive pressure attachment

A small bellows is synchronized with the large bellows of the Kifa respirator, rhythmically blowing air into the patient via an endotracheal tube. Pressures can easily be kept within physiological limits and as the machine is cam-actuated it is possible to produce a physiological pressure curve. There is no suction in the expiratory phase

In the post-acute phase this machine proved very valuable in tracheotomized patients. It is extremely reliable and may be used with the Kifa cuirass. The extra cost of furnishing the Kifa respirator with the Gullberg attachment is not very high. In the weaning period it is a good respirator, because when using the Kifa respirator with the Gullberg attachment it is quite easy gradually to discard the latter and thus make it possible to close the tracheotomy. We have had no experience with this machine in the acute phase, but in our opinion it should be tried in suitable cases.

Manufacturers: *Kifa*, Stockholm, Sweden. Price, £120–150.

The Bang Respirator (Bang, 1953)

This is a pressure-sensitive electrical respirator. (Figs. 33 and 34) It is quite an ingenious solution of the problem of producing intratracheal positive pressure ventilation by mechanical means, and the

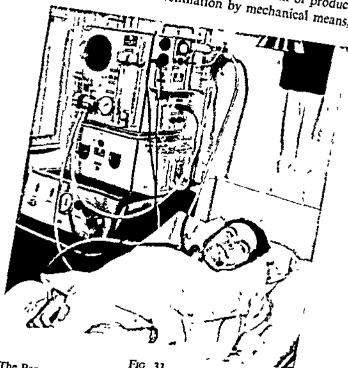


Fig 33
The Bang respirator in action latest model with humidifier.

Bang respirator has proved effective in many patients in the post-acute and chronic stages. The respirator can be so set that physiological pressure curves are obtained (Fig 35), and in the newest type suction can be applied to the expiratory phase. A very effective

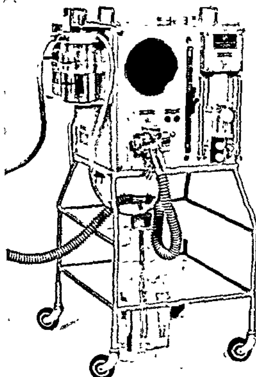


Fig 34
The Bang respirator latest model with electric humidifier

humidifying device is attached which can secure 100 per cent. humidity at body temperature This is done by warming the efferent rubber tubes electrically. We have only used this machine a few times in acutely ill, *wet* patients, but it seemed to work quite satisfactorily The newest type with suction during expiration should be well worth trying in acute patients with a cuffed tube, *i e.* in patients

being ventilated in a system without leakage. When the cuffed tube is replaced by an ordinary silver cannula, where leakage is considerable, the Bang respirator is still effective when the patient is awake, but

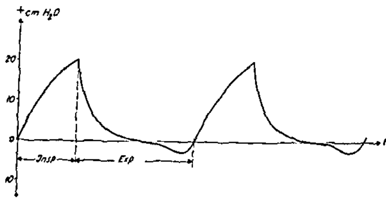


FIG 35
Pressure curve, Bang respirator.

during sleep this pressure-sensitive respirator may stop because of excessive leakage from the open mouth of the patient.

Manufacturers: Bang and Olufsen, Struer, Denmark.

The price of the Bang respirator is about one fourth that of a cuirass or tank respirator.

The Aga Respirator

This pressure-sensitive respirator is based on the ejector system. The driving force is compressed air or a compressed oxygen mixture.

The Aga is thus independent of electric current. It is easily handled, extremely reliable and has been used for more than two years in chronic patients, with satisfactory results. We have no experience with it in acute patients, but no doubt it could also be used in the acute phase

The maximal inspiratory capacity is sixty litres per minute. During expiration the pressure comes abruptly down to two millimetres of water with a flow of twenty-five litres per minute As in the Bang respirator, the pressure-regulated Aga machine stops if there is too much leakage The newest models include a device for securing a negative phase during expiration

Manufacturers: *Aga Gas Accumulator*, Stockholm, Sweden. The price is about £150.



Fig 36
Aga positive-pressure respirator with non-return valve

The Lundia Respirator (Fig 37)

Mechanically very simple and reliable, this machine is easy to handle manually in case of failure of the motor. By compression of a bellows a known volume of air or oxygen mixture is insufflated either by way of a mask or via an endotracheal tube. A safety valve in the semi-closed system set at 300 mm water guards against too high pressures. The maximal tidal volume is two and a half litres per cycle which will secure adequate alveolar ventilation even in

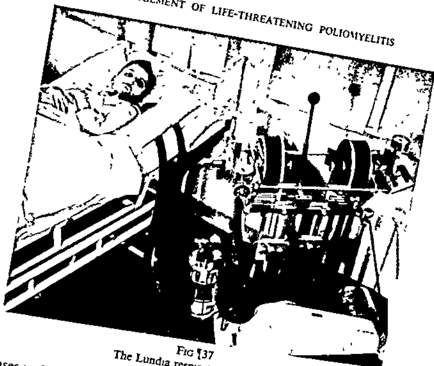


FIG 137
The Lundia respirator in action

cases with considerable leakage. The rate per minute may gradually be varied between ten and thirty. As the bellows is cam-actuated the pressure curve closely resembles physiological curves. Adequate moisture of the inspired air is secured through a good humidifier, thermostatically regulated. So far, our experience with the Lundia is limited to a few cases In one of these the machine has been in use for more than a year to our complete satisfaction. We think it should be tried in acute cases especially as in the newest models suction can be applied during the expiratory phase.

Manufacturers: *AB Instrumenta*, Lund, Sweden Price about £400.

The Mechanical Rocking Bed

This should only be used in *dry* cases of respiratory poliomyelitis in which the reduction in vital capacity is not too severe. Its place in the treatment of acute poliomyelitis with respiratory failure is rather limited On the other hand, it is often very useful in the weaning period and in the chronic stage, and probably has a beneficial effect upon the circulation and muscle tone.



FIG 38
Emerson rocking bed.

The Electrophrenic Respirator (Sarnoff *et al*, 1950)

This respirator has been used only a few times in our hospital and the results were unconvincing. It is a type of ventilation difficult to administer; it demands the constant presence of a physician at the bed-side and cannot be used for prolonged periods of time

CHAPTER IX

THE ACUTE STAGE: LUNG PHYSIOTHERAPY

BY E. ANDERSSON

LUNG physiotherapy should be given only by specially trained physiotherapists. In our treatment of patients suffering from respiratory insufficiency, with or without impairment of swallowing we had two objectives:

1. The maintenance of clear air passages.
   a. postural drainage
   b. squeezing and patting (tapôtement)
   c. suction.
2. The training of the respiratory muscles.

THE MAINTENANCE OF CLEAR AIR PASSAGES

Postural Drainage

The important postures for drainage are: lying on the right or left side with the foot of the bed elevated and lying on the stomach, together with combinations of these postures

We used special drainage beds, both ends of which as well as the middle part could be elevated (Fig 39). An ordinary bed can be elevated by means of blocks of wood or chairs. Sometimes, especially in children, the hips are raised by means of two wedge-shaped bolsters placed under the mattress with the patient lying prone. The foot or middle part of the bed is elevated in cases of atelectasis in the lower lobes or in the middle lobe, whereas the head end is elevated when atelectasis is located in the upper lobes. At first the patient is turned at intervals of half to one hour alternately lying on the right or left side If the atelectasis is located in the right lung the patient should preferably lie on his left side—and vice versa. During these manipulations care should be taken not to twist or bend the cuff-tube in the trachea causing it to slip out of the tracheal opening or to become displaced downwards, so that it passes the carina and enters the right main bronchus.

As far as possible the daily treatment should take place not only with the patient lying on his back but also on his right or left side and later also in the prone position.



FIG 39
Special drainage bed

Squeezing and Patting

Squeezing or vibrations are given in the form of a powerful, gradually increasing, vibrating pressure exerted with the palm during expiration and coordinated with the movements of the chest. This form of treatment is applied to the anterior lateral and posterior parts of the thorax for the purpose of loosening secretions.

Patting (tapôtement) is given with a hollow hand and loose wrist. The intensity of patting—like that of squeezing—depends upon the state of the patient and the tenderness of the chest wall This treatment is applied preferably to the lateral and posterior aspects of the thorax Patting also serves to loosen secretions.

If secretions are tenacious it may be necessary to resort to spraying the bronchial tree with various remedies, and to frequent application of hot compresses to the chest Adequate humidification influences favourably the consistency and amount of secretions Furthermore, secretions seem to loosen more readily if the patient is thoroughly ventilated under increased pressure prior to this form of treatment.

Suction

Tracheal secretions are sucked out through the rubber or silver tube, and the inner tube, removed from the silver cannula, is cleansed Suction is carried out by introducing a Tiemann catheter into the trachea through the endotracheal tube.

In the beginning there is often in addition, abundant secretion in the nose and mouth which should be likewise removed by suction. Here the suction is carried out by means of a Nélaton catheter. This catheter is kept in a jar with distilled water, whereas the tracheal catheter is kept in 0 1 per cent. rodalon[1] solution and washed in 5 per cent: bicarbonate solution before its insertion.

If, during artificial ventilation, the insufflation meets resistance, it will usually be due to partial or complete obturation of the tube from crust formation, and the tube will then have to be changed. Or the tube may become clogged from accumulation of secretions in the trachea and main bronchi; the patient should then be treated with lung physiotherapy and thorough suction. During suction, strong squeezing is applied, and the patient's attempt at coughing should be supported.

The duration of lung physiotherapy depends upon the general condition of the patient, but early in the disease tracheal suction should not be continued for more than half a minute at a time.

The individual therapeutic measures are discontinued.

1. when the respiration sounds free and no secretory *rattling* is palpable
2. when no more secretion is withdrawn by suction
3. when the consistency of the secretions changes from a purulent to a serous, non-tenacious character
4. when all parts of the chest are moving freely and symmetrically with ventilation.

In many patients rather protracted physiotherapy is well tolerated. Very ill patients, however, can stand this form of treatment only for a very short time and in such cases frequent brief applications are preferable. Often it is possible by intensive lung physiotherapy to clear areas of atelectasis within a very short time.

[1] $C_6H_5CH_2N(CH_3)_2RCl$

TRAINING OF THE RESPIRATORY MUSCLES

When the patient's lungs are free of secretions his spontaneous respiration should be exercised and trained whenever possible. First his respiratory movements are watched during artificial ventilation This is then discontinued and the patient told to keep on breathing with the same rhythm To begin with the respiratory movements should be followed and supported manually, as this tends to alleviate the patient's fear of having to breathe by himself As a rule these exercises will be limited to diaphragmatic respiration, the patient being told to relax the accessory respiratory muscles as far as possible. Here expiration may be enhanced by slight pressure upon the lateral parts of the chest In diaphragmatic respiration the patient should be directed during expiration to contract the upper abdominal muscles as far as possible and retract the lower anterior ribs. During inspiration, on the other hand, the abdominal muscles should be relaxed so that the downward movement of the diaphragm is facilitated and the abdominal wall moves forward

At first an attempt is made to let the patient breathe spontaneously merely for one minute or less every hour Later on spontaneous breathing is increased gradually Although it is very important that the patient should be encouraged to do his very best, he should never be allowed to become exhausted It is of decisive importance that the patient breathes by himself as soon as possible, because otherwise the increasing rigidity of the thoracic cage will offer too great a resistance for the partially paralysed muscles

Gradually, as spontaneous respiration improves and secretions diminish, the training of the respiratory muscles is increasingly stressed

The aim in training the respiratory muscles is

1 to build up their power and thus increase the vital capacity and
2 to coordinate the respiratory movements

Both the inspiratory and the expiratory muscles should be trained. The thoracic muscles are exercised by segmental expansion of the various parts of the chest the lower lateral, the upper lateral, the apical and the posterior. The expanding exercises are given by applying steadily increasing resistance to the patient's chest. The

resistance is effected by pressure of the hand of the physiotherapist, of the patient's hand or of a belt during the inspiratory movement—*i.e.*, during inspiration the patient attempts to force his ribs out against the pressure applied to the lateral aspects of the chest. Finally, this pressure is relaxed so that the last part of the inspiratory movement can proceed freely. During expiration the hand of the therapist follows the movements loosely, and finally exerts a slight pressure. The patient now tries to localise the movements to the very area where the hand is resting and to relax the rest of the chest and the cervical musculature

The expiratory muscles are exercised by strong contraction of the thoracic and abdominal muscles (*e.g.*, by blowing or by sounding 's').

Coughing is exercised as a vigorous, rather short expiratory movement. It is often replaced by clearing the throat, which may also clear the upper air passages even though this requires more muscular power.

Finally the patient exercises coordination of the thoracic and diaphragmatic movements at a steady and normal rate with simultaneous relaxation of the overworked cervical muscles.

DECANNULATION

The tracheal tube is often removed while the respiratory muscles are still contracting weakly. Hence, in the first weeks after decannulation it will often be necessary to treat the patient three to four times daily with postural drainage, preferably in the prone position, and to apply squeezing and patting, assistance in coughing and sometimes also suction through the tracheostoma in order to avoid accumulation of secretions, development of atelectasis—and, of course, the need for recannulation.

When secondary suturing of the tracheal stoma has been carried out, lung physiotherapy must be conducted with particular care and the abundant secretion which often accumulates must be eased up by support of the respiratory movements.

In order to avoid atelectasis in intercurrent infections of the upper air passages, patients with a low vital capacity should always be treated with lung physiotherapy under such conditions—in particular, by postural drainage and manual assistance in coughing

In patients with severely deficient spontaneous respiration who require positive-pressure ventilation it is necessary to carry out lung physiotherapy with great persistence in order to keep the lungs clear. Finally, it should be emphasised that attempts should be made continuously to exercise spontaneous respiration—not least for psychological reasons.

CHAPTER X

THE ACUTE STAGE: COMPLICATIONS AND SPECIAL CONDITIONS

BY J. PEDERSEN AND K. BJERRE-CHRISTENSEN

THE most important complications and special conditions which may be encountered in life-threatening poliomyelitis are: circulatory shock, hyperpyrexia, azotaemia and uraemia, pulmonary oedema, paralytic ileus and hypertension.

Although these complications have been recognized for some time their significance, interrelationship and eventual prognosis have not always been estimated correctly. Thus, none of us had fully realized that these complications would influence the clinical picture of the disease to the extent which was actually observed.

TABLE X

COMPLICATIONS, INCIDENCE AND RELATION TO MORTALITY. 345 CASES MORTALITY 42 PER CENT

Complications	Incidence		Mortality	
	No of cases	Per cent.	No of cases	Per cent
Shock	134	39	90	67
Hyperpyrexia	66	19	60	91
Uraemia*	36	22	28	78
Pulmonary oedema	29	8	26	93
Paralytic ileus	112	32	49	44
Hypertension	65	19	27	42

* Only patients of age 15 years or more

Table X gives the frequency of the various complications and their relation to mortality. The figures reported give the number of patients who had the respective complication at least once. As to the occurrence of uraemia, regard is paid only to adult patients; children were not examined in this respect so regularly that reliable statistical data could be obtained.

It will be noted that shock, hyperpyrexia and uraemia are the most important complications. They appear very frequently, and are prognostically unfavourable. Pulmonary oedema is still more dangerous, although less frequent. Paralytic ileus and hypertension are almost as common as the three first-mentioned complications, but they do not carry the same increase in mortality

CIRCULATORY SHOCK

This term designates a circulatory insufficiency, in which the following well-known signs are found lethargy, haemoconcentration, a decrease in circulating blood volume, feeble pulse, pale and clammy extremities with a delayed filling of the capillaries, cyanotic nails and —in the most severe cases—mottled cyanosis of the skin. Usually, the blood pressure is low in this condition, but in poliomyelitis a state of shock may exist simultaneously with normal—or even increased—blood pressure An excellent survey of modern concepts of shock has been given by Frank (1953).

In poliomyelitis the state of shock presumably is due to disturbances in tissue metabolism on account of hypoxia or hypercapnia and to the effects of toxic or infectious (viral) agencies In many cases the mechanism seems to be of complex nature Here mention will be made only of the importance of artificial ventilation and the significance of incorrectly administered positive pressure ventilation (Werko, 1947) If the intrapulmonary pressure during expiration does not rapidly fall to zero, the venous return to the right heart is hampered This lowers the minute volume which in turn promotes a condition of shock

In our series, shock often occurred in the first stages of the disease, before artificial ventilation was instituted, and quite commonly as a terminal event Thus the great frequency of shock cannot be explained as solely attributable to the introduction of manual positive pressure ventilation even though this occasionally may have promoted its appearance It seems more reasonable to assume that the high incidence in this series is due chiefly to the severity of the poliomyelitic infection In addition there is no doubt that the importance of shock in infectious diseases and the deleterious effect of cerebral hypoxia is steadily gaining more attention.

The treatment of shock consisted of intravenous infusions of blood, plasma and plasma substitutes and, as experience increased in the

course of the epidemic, these therapeutic measures were instituted before the state of shock had fully developed.

Such treatment had a favourable effect in cases of initial or early shock. In fully developed cases its effectiveness was less because in them it was often impossible to restore circulation to normal. The vessels lose their tone, and blood accumulates on the venous side: a state of irreversible shock (Wiggers, 1947) develops. In such cases we sometimes used intravenous infusions of noradrenaline and on a few occasions tried an intra-arterial infusion of blood, without, however, beneficial result.

In our opinion, the recognition of incipient shock and its prompt treatment constitutes a great advance in the management of severe poliomyelitis. Furthermore, it is important to realize that the patient, whose respiratory insufficiency is of moderate extent may be so improved as a result of the restoration of the blood volume that the respiratory insufficiency seems to be less serious than at first assumed. Such improvement may suggest that a contributory factor has been the presence of early signs of shock.

Fully developed shock is a dangerous sign, and it appears to aggravate the final prognosis even in cases where it seems to subside under adequate treatment. No doubt pressor-amines such as noradrenaline should be given a trial in initial shock accompanied by a low blood pressure, as some danger of fluid over-loading is attached to the usual treatment.

HYPERPYREXIA

Here the term is defined as a body temperature of at least 39° C. (102 2° F.) until death or consecutively for the first five days after admission. By this definition we have tried to exclude cases of hyperpyrexia due to secondary complications (*e.g.*, pneumonia). With a frequency of about twenty per cent. (Table X), hyperpyrexia was a characteristic feature of the epidemic and an ominous prognostic sign.

The regulation of the body temperature is a highly coordinated function which presupposes that the hypothalamic region is not seriously involved in the morbid condition, but it must be admitted that the pathogenesis of hyperpyrexia is not fully understood.

In dealing with hyperpyrexia we employed such physical measures as uncovering of the skin or covering the patient with thin wet

sheets We did not try to induce controllable hypothermia—artificial hibernation (Laborit and Huguenard, 1951)—although such treatment might perhaps have improved the prognosis in some cases. It should no doubt be tried in suitable cases.

There appears to be a distinct correlation between hyperpyrexia and shock, and it seems possible that the former is an essential preliminary to the development of shock

AZOTAEMIA AND URAEMIA

A moderate increase in nonprotein nitrogen (NPN) is a characteristic finding in poliomyelitis as well as in other severe infectious diseases. This form of azotaemia is of the prerenal type and often persists longer in poliomyelitis than in other diseases—due in part to the marked decomposition of muscle protein in paralytic poliomyelitis. Pronounced azoturia is another sign of this tissue decomposition

Here the term uraemia is defined as a nonprotein nitrogen content amounting to 100 mg per cent or more. This was found particularly in those patients who developed true renal uraemia after a severe, more or less protracted, state of shock This form of acute ischaemic damage to the kidneys manifests itself clinically by anuria or oliguria and decreased concentrating power—a condition which has various clinical designations—"shock" kidney, acute tubular necrosis, acute cortical necrosis, lower nephron nephrosis, etc In some cases this condition may have been actuated by blood transfusions

Among seventy-four adult patients with shock thirty-six developed such a form of acute ischaemic renal failure In most cases the diagnosis was confirmed by autopsy findings The prognosis was very serious as twenty-eight out of thirty-six patients (seventy-eight per cent) died

Our treatment was conservative and a slight modification of the one used by Bull, Jockes and Lowe (1949). Manifest shock as we have already said was treated by transfusions Fluids were administered only after daily determination of fluid loss and intake In some cases correction of the electrolytes towards normal values was tried. For feeding we employed an electrolyte and protein-free, high-calorific emulsion of glucose, starch and oil by stomach tube, given in amounts corresponding to 500–2,000 calories per day. In some cases hyper-

tonic glucose was given intravenously Dialysis of the blood was not employed.

A survey of the problems involved in acute ischaemic renal insufficiency has been given by Brun (1954)

PULMONARY OEDEMA

The classical clinical picture of pulmonary oedema—dyspnoea and cyanosis, cold and sweaty skin, persistent cough, and watery, foamy expectoration often tinged with blood—was rare in our cases. Most often dyspnoea and cyanosis were inconspicuous, coughing was ineffective or entirely absent although numerous râles were heard all over the chest. Copious fluid with the appearances described above could be obtained by intratracheal suction. These were the main diagnostic features. Pulmonary oedema was observed most often as a terminal event but in a few cases was noted after the clearing of bronchial obstruction

In most instances, it seems likely that pulmonary oedema was due to a combination of various factors: bronchial obstruction, hypoxic capillary paralysis, damage to the heart or vasomotor disturbances in the lungs elicited by changes in the central nervous system No doubt, in a few cases it was due to overdosage of intravenous infusions.

In dealing with pulmonary oedema we employed a variety of measures Elevation of the head end of the bed, an oxygen supply under increased positive pressure, alcohol in the humidifier of the oxygen flask, infusion of concentrated plasma or ten per cent. non-electrolytic dextran were all used at some time or another. Now and then venesection was done, and attempts at bloodless venesection by application of tourniquets to the extremities, combined with arterial infusions of blood were occasionally used.

Although we gradually developed a comprehensive therapeutic system to deal with pulmonary oedema it was—as appears from Table X—of very little effect. Often the oedema would subside temporarily, but in nearly all cases it returned. The pronounced hypoxia and haemoconcentration accompanying accumulation of secretions in the lungs frequently initiated a state of shock, and this combination of shock and pulmonary oedema always terminated fatally On the whole, the prognosis of patients with pulmonary oedema was exceedingly poor

PARALYTIC ILEUS

We have defined paralytic ileus as a syndrome characterized by impairment or total cessation of intestinal motility, distention of the intestines, intermittent vomiting and lack of bowel evacuation Under this heading we also include acute atonic dilatation of the stomach As is evident from Table X this complication was frequently observed.

The pathogenesis is complex central autonomic disturbances, circulatory failure with hypoxia of the intestinal wall and altered capillary permeability as well as fluid and electrolyte disturbances may all play a contributory rôle. In our cases there was no constant relationship between hypopotassaemia and paralytic ileus

Paralytic ileus carries with it a risk of aspiration of vomitus Furthermore, the movements of the diaphragm are impeded by the increased intra-abdominal pressure, and postural drainage is rendered difficult

The treatment of paralytic ileus was, however, encouraging Permanent intubation of the stomach and continuous intestinal drainage by suction, the correction of electrolyte disturbances, parenteral nourishment, and in some cases anti-shock therapy together with prostigmine and high rectal enemata—one or other or a combination of these usually rapidly re-established intestinal function.

The final prognosis was not definitely aggravated by this complication presumably because the most serious risk, aspiration of vomitus into the lungs, was counteracted effectively by the cuff-tube in the trachea.

HYPERTENSION

Our definition of this term is a systolic blood pressure of at least 150 mm mercury in adults, or 120 mm mercury in children, present for at least twenty-four hours consecutively, as determined by palpation of the radial artery

Variation of the blood pressure constitutes an early and reliable means of revealing inadequate ventilation and circulation, because increased CO_2 tension and lowered O_2 tension as a rule lead to hypertension, and circulatory shock most often is accompanied by a low blood pressure The blood pressure was measured very often in our patients—in the acute stage about every thirty to sixty minutes

throughout the twenty-four hours—and *blood pressure readings* have been one of our most important methods of examination.

Besides hypertension *due to hypercapnia and hypoxia*, we often encountered a rather fixed state of hypertension *in patients without* any particular biochemical changes of the blood. *The hypertension manifested itself by a systolic pressure of about* 200 mm. mercury, and often it persisted through many months. *As a rule, the blood* pressure returned to normal sooner or later, but in some of our patients *some degree of hypertension still exists—more than three* years after the onset of the illness.

Clinically, it is important to be acquainted with this form of hypertension *which is unrelated to hypercapnia or hypoxia. If* patients with *this form of hypertension developed hypercapnia the* blood pressure increased further, *e.g.* from 180 mm. systolic to 230 mm. and came back to about 180 mm. when the hypercapnia was abolished In cases of shock *the reaction was of a similar character.* Thus if the patient had circulatory *shock the systolic blood pressure might* [illegible] to 180 mm

[illegible]

abnormally high level *was quite conspicuous in* several patients with total paralysis. They were in a state of *hyperpyrexia* and pronounced circulatory insufficiency with clammy extremities and haemoconcentration but well-ventilated and with a systolic pressure of about 200 mm. mercury *Only terminally* did the blood pressure fall, *often accompanying the development of pulmonary* oedema.

It would, therefore, seem practicable to differentiate two groups of shocked patients *both of which have a high normal or increased* blood pressure *One group has poliomyelitic hypertension* When the shock subsides the blood pressure *rises.* In the other group hypertension is due to *hypercapnia or hypoxia. When the hyper*capnia or hypoxia *subsides in* these patients, the blood pressure falls to usual shock levels, and returns to normal when the shock is abolished.

From Table X it will be observed *that* hypertension was encountered in about one-fifth of our patients *and that its presence* was not [illegible] mortality

[illegible] ously

[illegible] d in

paralytic patients without respiratory insufficiency, but here it is less pronounced and of a shorter duration.

As will be pointed out below, the frequency of hypertension appears to be correlated with the extent of paralysis of the respiratory muscles, and possibly of other muscles too. In contrast to previous experience, hypertension did not occur in our group (A) of patients with polio-encephalitis (Tables XI (a) and XI (b)) This appears to be out of conformity with the view that this form of hypertension is due principally to poliomyelitic lesions of the autonomous centres in the brain stem (the reticular formation of the medulla oblongata and the hypothalamus)

The secretion of noradrenaline is known to be increased in states of emergency and conditions of stress In a few patients with hypertension we have examined the urinary excretion of adrenaline-noradrenaline without finding any increase. We have not examined any patients for the presence of renal vasomotor exciting material, but it is obvious that neither this mechanism nor the renin-angiotonin mechanism is the cause of this type of hypertension.

Increased secretion of adrenal cortical hormones in situations of stress is well-established, and hypertension as part of the general adaptation syndrome has been described by Selye (1948) This hypertension is usually of a temporary nature, *e.g.*, the blast hypertension, observed in victims of the Texas City disaster (Ruskin *et al*, 1948), disappeared within ten to fourteen days after the injury The hypertension described by Graham (1945) as occurring in 27 per cent. of 695 soldiers during battle-strain was only found in five of thirty-three hypertensives, re-examined two months later In some of our patients chosen at random, we examined the urinary excretion of 17-ketosteroids and 11-oxysteroids (corticoids) We were not able to establish convincing correlation between hypertension and increased corticoid output, for hypertension was observed in several patients who showed a normal output

It should be mentioned that none of our patients gave a history of essential hypertension, and none presented any evidence of hypertension of nephritic origin It is quite obvious that an adequate explanation of the origin of this sustained hypertension is still lacking

Having thus reviewed the different complications and special conditions it is now proposed to survey their occurrence in the different subgroups of the present series

RELATIONSHIP OF COMPLICATIONS TO THE MAIN CLASSIFICATION OF POLIOMYELITIS

Tables XI(a) and XI(b) *give a survey of the distribution of the* complications in the various subgroups of the series.

TABLE XI(a)

INCIDENCE OF COMPLICATIONS IN RELATION TO MAIN CLASSIFICATION OF CASES (345)

Group	No. of cases	Deaths		Incidence													
				Shock		Hyper-pyrexia		Urae-mia*		Oedema of lungs		Ileus		Hyper-tension			
		No	%	No	%	No	%	No	%	No	%	No	%	No	%		
A	75	29	39	30	40	14	19	4	(36)	11	15	16	21	2	3		
B	*12*	*3*	*(25)*	*1*	*(8)*	*3*	*(25)*	*1*	*(33)*	*1*	*(8)*	*0*	*(0)*	*2*	*(17)*		
C	157	50	32	47	30	17	11	10	11	8	5	55	35	33	21		
D	28	13	46	12	43	6	21	2	10	2	7	9	32	4	14		
E	60	38	63	35	58	18	30	14	45	5	9	25	42	20	33		
F	13	11	85	9	69	8	62	5	50	2	(15)	7	54	4	31		
Total	345	144	42	134	39	66	19	36	22	29	8	112	32	65	19		

* Only patients of age 15 years or more

TABLE XI(b)

SUMMARY OF TABLE XI(a)

Groups	No of cases	Deaths		Incidence											
				Shock		Hyper-pyrexia		Urae-mia*		Oedema of lungs		Ileus		Hyper-tension	
		No	%	No	%	No	%	No.	%	No	%	No	%	No.	%
A+B	87	32	37	31	36	17	20	5	36	12	14	16	18	4	5
C+D	185	63	34	59	32	23	12	12	11	10	5	64	35	37	20
E+F	73	49	67	44	60	26	36	19	46	7	10	32	44	24	33

* Only patients of age 15 years or more

From these tabulations it is evident that complications occurred most frequently in groups E and F.

The most serious complications (shock, hyperpyrexia and uraemia) present more or less the same pattern of frequency distribution in the various subgroups, and this pattern is the same as that seen in the distribution of the mortality. This fact lends some support to the assumption of a causative inter-relationship between them, as mentioned before

Oedema of the lungs seems to be found especially in the groups with polio-encephalitis and cerebralia The reason might be, that oedema of the lung is due in particular to neurogenic vasomotor disturbance of the pulmonary circulation

It is interesting that paralytic ileus is rather frequent in the spinal respiratory paralysis group (C+D), and thus does not follow very closely the distribution of shock

The most conspicuous feature is that hypertension is almost absent in the polio-encephalitis group, while it is frequent in the cerebralia groups (E+F) and more frequent in group C—clear-cut spinal respiratory paralysis—than in group D, the spinobulbar group. The pattern of hypertension is thus correlated with the extent of the paralysis of the respiratory and possibly other muscle groups, which, as has already been mentioned, does not favour a view that hypertension is usually due to a polio-encephalitic process

Relation of Complications to Sex and Age

For the sake of easy survey the figures will be recorded only for four complications and in three groups of patients.

Table XII shows the close parallel between mortality and the presence of shock, hyperpyrexia and uraemia in adults. It is seen that the pattern of hypertension is similar for adults and children, and in the two sexes Thus, the absence of hypertension in our polio-encephalitic group is not due to the fact that the group comprises almost exclusively children and more boys than girls

A pronounced sex difference in mortality is found in one group group C+D in which it is much higher for males than for females, but of the same magnitude for adults and children Group E+F shows a difference between children and adults but no sex difference (Table XII)

The close association between high mortality and the occurrence of serious complications is not unexpected. In Table XIII it is apparent that the ratio of the number of serious complications (shock, hyperpyrexia, uraemia) to the number of deaths is nearly the same in the

TABLE XII

COMPLICATIONS IN RELATION TO SEX AND AGE IN DIFFERENT GROUPS OF POLIOMYELITIS

Polio Group	Age: 15 years and more: Total No of cases	Deaths		Shock		Hyper-pyrexia		Uraemia		Hyper-tension		Age: 14 years and less: Total No of cases	Deaths		Shock		Hyper-pyrexia		Hyper-tension	
		No	%	No	%	No	%	No	%	No.	%		No	%	No.	%	No	%	No.	%
Males A+B	5	3	(60)	3	(60)	2	(40)	2	(40)	0	(0)	51	16	31	17	33	11	22	4	8
C+D	55	23	42	24	44	8	15	11	20	16	29	38	16	41	11	29	6	16	6	16
E+F	28	23	82	22	78	14	50	13	46	9	32	19	11	(58)	9	(47)	3	(16)	6	(31)
Total	88	49	56	49	56	24	27	26	30	25	28	108	43	40	37	34	20	18	16	15
Females A+B	9	4	(45)	3	(33)	1	(11)	3	(33)	0	(0)	22	9	41	8	36	3	14	0	0
C+D	55	14	25	14	25	6	11	1	2	6	11	37	10	27	10	27	3	8	9	24
E+F	13	10	(77)	8	(60)	6	(46)	6	(46)	3	(23)	13	5	(38)	5	(38)	3	(23)	6	(46)
Total	77	28	35	25	32	13	17	10	13	9	12	72	24	33	23	32	9	13	15	21

four groups Likewise the higher mortality for adult males (fifty-five per cent.) in the whole series is readily explained by the fact that thirty-two per cent of the males, but only eighteen per cent. of the females and children fall into groups E and F, in which the number of serious complications and, consequently, the mortality is particularly high This clearly illustrates the great significance of these complications in the prognosis.

In regard to pathogenesis the complications and special conditions mentioned in this chapter obviously differ in their relation to the

TABLE XIII

MORTALITY AND NUMBER OF SERIOUS COMPLICATIONS IN RELATION TO SEX AND AGE

Polio groups	C+D		E+F	
Sex and age	Males	Females	Children	Adults
Total No of cases	93	92	32	41
1 No of serious complications *	60	34	20	50
2 No of deaths	39	24	16	33
Deaths in percentage	42	26	50	80
Ratio 1 2	1 5	1 4	1 3	1 5

* Shock, hyperpyrexia, uraemia

poliomyelitic infection The main argument for discussing them in one group is the fact that they are essential to the adequate observation of the patient during the acute stage. Some of them are amenable to direct therapeutic measures, and some are of decisive significance to the prognosis. As was to be expected differences in mortality were proportionate to the degree of occurrence of serious complications.

Finally, we have to mention that the total frequency of these complications is not evident from the figures given, because one and the same complication occurred more than once in individual patients If the total number be included in the calculation the average number of complications was two per patient This gives an impression of how severe was the 1952 epidemic

TABLE XII

COMPLICATIONS IN RELATION TO SEX AND AGE IN DIFFERENT GROUPS OF POLIOMYELITIS

Polio Group	Age: 15 years and more: Total No of cases	Deaths No.	Deaths %	Shock No.	Shock %	Hyper-pyrexia No.	Hyper-pyrexia %	Uraemia No.	Uraemia %	Hyper-tension No	Hyper-tension %	14 years and less: Total No. of cases	Deaths No.	Deaths %	Shock No.	Shock %	Hyper-pyrexia No	Hyper-pyrexia %	Hyper-tension No.	Hyper-tension %
Males A+B	5	3	(60)	3	(60)	2	(40)	2	(40)	0	(0)	51	16	31	17	33	11	22	4	8
C+D	55	23	42	24	44	8	15	11	20	16	29	38	16	41	11	29	6	16	6	16
E+F	28	23	82	22	78	14	50	13	46	9	32	19	11	(58)	9	(47)	3	(16)	6	(31)
Total	88	49	56	49	56	24	27	26	30	25	28	108	43	40	37	34	20	18	16	15
Females A+B	9	4	(45)	3	(33)	1	(11)	3	(33)	0	(0)	22	9	41	8	36	3	14	0	0
C+D	55	14	25	14	25	6	11	1	2	6	11	37	10	27	10	27	3	8	9	24
E+F	13	10	(77)	8	(60)	6	(46)	6	(46)	3	(23)	13	5	(38)	5	(38)	3	(23)	6	(46)
Total	77	28	35	25	32	13	17	10	13	9	12	72	24	33	23	32	9	13	15	21

four groups. Likewise the higher mortality for adult males (fifty-five per cent) in the whole series is readily explained by the fact that thirty-two per cent of the males, but only eighteen per cent. of the females and children fall into groups E and F, in which the number of serious complications and, consequently, the mortality is particularly high. This clearly illustrates the great significance of these complications in the prognosis.

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Ratio 1 2	1 5	1 4	1 3	1 5

* Shock, hyperpyrexia, uraemia

poliomyelitic infection. The main argument for discussing them in one group is the fact that they are essential to the adequate observation of the patient during the acute stage Some of them are amenable to direct therapeutic measures, and some are of decisive significance to the prognosis. As was to be expected differences in mortality were proportionate to the degree of occurrence of serious complications

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CHAPTER XI

CONVALESCENT AND CHRONIC STAGE: COURSE OF RESPIRATORY PARALYSIS

By T Sottrup

Prior to the epidemic of 1952–53 the prognosis for patients with respiratory paralysis in Denmark was exceedingly poor. The great majority—eighty per cent.—of these patients died in spite of the use of respirators and other therapeutic measures. Through the altered therapeutic methods adopted, it proved possible in 1952 to reduce the mortality for such cases to an average of about forty per cent.—towards the end of the epidemic it was even lower—about twenty per cent. Thus we now have for critical analysis a number of surviving patients who have or have had respiratory insufficiency of varying degrees.

The series has been reviewed as at January 1, 1956, and comprises 345 patients with life-threatening forms of poliomyelitis. Group B—twelve patients—which consists of those who merely had pharyngeal-laryngeal paralysis but no respiratory insufficiency will not be dealt with here. There thus remains a total of 333 patients with respiratory insufficiency of slight, moderate, or severe degree.

The following review attempts to analyse both the evolution and the regression of respiratory paralysis. The fatal cases and the survivors will be dealt with separately

THE FATAL CASES

Time of Death

This is evident from Table XIV, the time being reckoned from the day of admission.

From Table XIV it will be noted that sixty-nine per cent. of the deaths occurred within the first week of hospitalization. Of the total number of patients who had died by January 1, 1956, no less than one-fifth died within the first twenty-four hours in hospital. Altogether ninety-two per cent of the deaths occurred within the first month. After this only eleven patients died Thus the danger of a fatal

outcome in a given case is postponed indefinitely after the first month of illness. It may be noted that all patients in the present series still alive at the time of this account—January 1, 1956—have been under observation for between thirty-five and forty-three months

TABLE XIV

141 DEATHS AMONG 333 PATIENTS WITH RESPIRATORY INSUFFICIENCY IN GROUPS A, C, D, E AND F, DISTRIBUTED ACCORDING TO THE TIME OF DEATH AS RECKONED FROM THEIR ADMISSION

Died after	less than 24 hours	more than 24 hours – less than 7 days	more than 7 days – less than 1 month	more than 1 month
Group A	13	13	3	—
Group C	9	29	9	3
Group D	2	8	1	2
Group E	1	18	14	5
Group F	1	3	6	1
Total	26	71	33	11
% of 141	19%	50%	23%	8%

Evolutionary period of respiratory insufficiency

It is often difficult to establish chronologically the exact time of appearance of the first symptoms of respiratory insufficiency The evolutionary period may be defined as the number of days from the commencement of the second febrile wave to the unquestionable appearance of symptoms of respiratory insufficiency—or, if only one febrile wave can be demonstrated, from the onset of this

Respiratory insufficiency in poliomyelitis usually develops rapidly, but because of the heavy pressure of work during the epidemic it was not always possible to record all clinical data precisely

From Table XV, covering all 333 patients, it is evident that the mortality was highest (fifty-three per cent.) in those patients whose respiratory insufficiency developed very rapidly, *i.e.*, within forty-eight hours In this respect it did not make any difference whether the respiratory insufficiency developed within two to four days or later

Table XVI shows the variations in this respect in the various groups of patients (A, C+D and E+F) For the sake of simplicity, a distinction is made here only between an evolutionary period not exceeding forty-eight hours, and a period over forty-eight hours

TABLE XV

EVOLUTION TIME OF RESPIRATORY INSUFFICIENCY IN 333 PATIENTS

Evolution time	No of Pts.	Deaths	Mortality rate
not established	24	6	(25%)
less than 2 days	160	85	53%
between 2 and 4 days	103	35	34%
more than 4 days	46	15	33%
Total	333	141	42%

TABLE XVI

EVOLUTION TIME OF RESPIRATORY INSUFFICIENCY ACCORDING TO CLINICAL CLASSIFICATION

Evolution time of respiratory insufficiency		A	C+D	E+F	Total
less than 2 days	No	37	82	41	160
	Deaths	19	36	30	85
	Mortality Rate	50%	44%	73%	53%
longer than 2 days	No	28	90	31	149
	Deaths	7	25	18	50
	Mortality Rate	25%	28%	58%	34%

Furthermore, the cases without definite data concerning the evolutionary period have been excluded, because such patients in the present series were distributed equally over the individual groups. Roughly speaking about one-half of the patients developed respiratory

insufficiency within forty-eight hours, the other half more slowly. In all groups the mortality was higher among the patients with the shorter evolutionary period—and this seems to apply especially to the patients with polio-encephalitis (Group A).

A further analysis revealed that among the 160 cases in whom respiratory insufficiency developed within forty-eight hours, no less than 85 died and of these nearly twenty-five per cent. died within twenty-four hours after admission. Among the 149 patients in whom respiratory insufficiency developed later, 50 died—but only ten per cent of them within twenty-four hours after admission. Here it should be kept in mind that the evolution of respiratory insufficiency often started at home, one or two days before admission.

Occurrence of severe paralysis of respiratory muscles

A detailed investigation of the 112 patients who died in Groups C, D, E and F shows—as indeed might be assumed—that all had severe paralysis of the diaphragm and the intercostal muscles. This was demonstrated clinically and most of them also showed fluoroscopic signs of bilateral massive paralysis of the diaphragm. These patients all required artificial ventilation right until their death.

Bilateral paralysis of the upper extremities

Although the appearance of paralysis of the upper extremities is a definite danger signal, indicating that respiratory insufficiency is imminent, the death rates of patients with respiratory failure and bilateral paralysis of the upper extremities are no higher than in patients with respiratory insufficiency without paralysis of the arms.

Incidence of cerebralia

As mentioned already, the concept of cerebralia is arbitrarily defined as follows: the syndrome is considered present if, after correction of biochemical disturbances in the acid-base status and of the oxygen saturation of the arterial blood has been attempted, a patient in the acute phase presents signs of drowsiness or coma for at least 48 hours.

The mortality for patients with respiratory paralysis and acute-stage signs of cerebralia is found to be particularly high, namely: sixty-three per cent. for group E, and eighty-five per cent. for group F. Respiratory paralysis is also found in groups C and D, both of

which have a lower mortality. However, according to the adopted classification of the patients in this survey, cerebralia is specific for groups E and F only. It would thus seem that the high mortality in these latter two groups may reasonably be attributed to cerebralia, since the treatment of all patients was essentially the same.

Accumulation of secretions in the air passages early in the disease

As previously mentioned, we have divided the patients into the following subgroups: *wet a* with secretions in the lungs and bronchi —*wet b* with secretions limited to the hypopharynx—and *dry* with no particular amount of secretions—all prior to treatment.

The following factors may play a rôle in the appearance of secretions in the air passages (1) true pharyngeal or laryngeal paralysis, (2) insufficient deglutition due to encephalitic haziness and debility, (3) cerebralia, with disturbances in the acid-base equilibrium or the oxygen saturation or both, (4) insufficient coughing due to diaphragmatic paralysis, and (5) faulty posture. As previously demonstrated, it is only the accumulation of secretions in the lower air passages that is of significance in the fatality rate—*i e.* group *wet a*—whereas it seems to make little difference whether the patient belongs to group *wet b* or to the *dry* group

THE SURVIVORS

Severity of respiratory paralysis

It is not surprising that a fair degree of conformity is demonstrable between the severity of respiratory insufficiency and the duration of artificial respiration. This period is here called ventilation time We are fully aware of the fact that respiratory neurosis in some patients may have delayed the regression but, as a matter of fact, this seemed to be the case only rarely and is therefore not considered here.

It will be observed from Fig 40 that in about thirty per cent. of cases (56 out of 194) artificial ventilation was not necessary. As to the remaining 138 patients the curve indicates that within the first two or three months of artificial ventilation the individual patient still had a good chance of regaining adequate spontaneous respiration, and that this applied in particular to the first two months. After six to nine months of artificial ventilation the prospects of recovering

full spontaneous respiration were only slight Thus, of the 102 patients who after one month still required artificial respiration, no

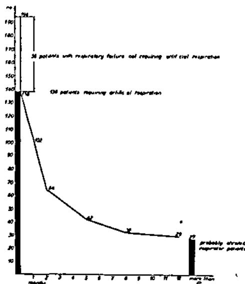


FIG 40

Distribution of 194 *survivors* with respiratory insufficiency in relation to the period of artificial respiration (ventilation time)

less than 43 had to be given artificial ventilation round the clock, including 25 patients who eventually became chronic respirator patients

Evolution time of respiratory insufficiency and duration of artificial respiration

In group A (polio-encephalitis) it will be of little interest to investigate this matter as these patients had only slight respiratory insufficiency and therefore required artificial respiration merely from a few days up to three weeks.

On more detailed analysis of groups C, D, E and F with 107, 15, 22 and 2 survivors respectively, the evolution times of respiratory insufficiency were found to be evenly distributed, so that they may be added together into one group.

From Table XVII it is evident that 39 per cent. of the survivors developed respiratory insufficiency within forty-eight hours, and that 74 per cent. developed respiratory insufficiency within four days. Furthermore, from the last column, it will be seen that 50 per cent. (18 per cent. plus 32 per cent.) recovered full spontaneous respiration within one month. On the other hand, nearly one-fourth

TABLE XVII

CORRELATION BETWEEN EVOLUTION TIME OF RESPIRATORY INSUFFICIENCY AND DURATION OF ARTIFICIAL VENTILATION (PARTIAL OR CONTINUOUS) IN 146 SURVIVORS —AS AT JANUARY 1, 1956—GROUPS C, D, E, AND F

Duration of artificial ventilation	Evolution of respiratory insufficiency					
	less than 2 days	between 2 and 4 days	more than 4 days	Unknown	Total	% of 146
None	11	9	5	2	27	18%
Less than one month	20	15	10	2	47	32%
One to six months	14	13	10	3	40	27%
More than six months	12	14	2	4	32	23%
Total	57	51	27	11	146	(100%)
% of 146	39%	35%	18%	8%	100%	—
Chronic respirator patients	9	13	1	2	25	17%

of the survivors (23 per cent) required assisted respiration for more than six months, and the majority of these patients—namely 25 out of 32—became chronic respirator patients. It is evident, moreover, that for the required ventilation time it makes no difference whether the evolution time of respiratory insufficiency is less than two days or between two and four days. Nor is this of any importance in determining whether the patient will become a chronic respirator patient In contrast Table XVII indicates, as shown before, that when respiratory insufficiency develops slowly, the chances of becoming a chronic case are definitely less. Thus the group with an

evolution time of more than four days includes only one chronic respirator patient

Incidence and significance of severe paralysis of the respiratory muscles

As already stated, all the fatal cases had severe paralysis of the respiratory muscles—except the patients in group A. The same applies to a majority of the survivors as is apparent from the fact that it was necessary to give them artificial ventilation for such a long time

TABLE XVIII

146 SURVIVORS WITH PARALYSIS OF RESPIRATORY MUSCLES (GROUPS C, D, E, AND F) IN RELATION TO CHARACTER OF RESPIRATORY PARALYSIS AND TO DURATION OF ARTIFICIAL VENTILATION

Artificial ventilation	Diaphragm paralysed only	Intercostals paralysed only	Both diaphragms and intercostals paralysed	Total
None	13	10	4	27
Less than one month	13	5	29	47
One to three months	1	—	21	22
Three to six months	1	—	17	18
More than six months	—	—	32	32
Total	28	15	103	146
Chronic respirator patients	—	—	25	25

In Table XVIII groups C, D, E and F include a total of 146 survivors as at January 1, 1956 Of these nearly 20 per cent had diaphragmatic paralysis alone, about 10 per cent had paralysis of the intercostal muscles alone, while the rest—about 70 per cent. (103 patients)—had paralysis of both these muscle groups.

The patients with paralysis of the diaphragm as well as of the intercostal muscles have a smaller chance of recovery. In this group only 33 patients (4 plus 29) had such a slight paralysis of the respiratory muscles that they recovered complete spontaneous respiration within one month of illness, whereas no less than 49 patients (17 plus 32) had such a severe paralysis of their respiratory muscles that they required artificial respiration for more than three months All the 25 patients—

who eventually were grouped as permanent respirator patients belonged to this category.

On comparison of the clinical estimation of respiratory insufficiency in patients with diaphragmatic paralysis and the motility of the diaphragm as estimated fluoroscopically, very good agreement was found between the two. Only in a minority of cases was the diaphragmatic paralysis bilateral and complete. A thorough fluoroscopic analysis showed that:

39 patients had unilateral, right, diaphragmatic paralysis
20 patients had unilateral, left, diaphragmatic paralysis
72 patients had bilateral diaphragmatic paralysis.

In cases of unilateral paralysis, thus, there is a predominance of right-sided paralysis. This may perhaps be due to the position of the liver, so that slight diaphragmatic paralysis on the right side may manifest its presence clinically more readily. Here it may also be mentioned that unilateral paralysis of the intercostal muscles is by no means rare.

Occurrence of true pharyngeal or laryngeal paralysis

This complication in the acute stage does not seem to prolong the ventilation time for the survivors

Occurrence of excessive secretions early in the disease

TABLE XIX

PATIENTS WITH RESPIRATORY INSUFFICIENCY (146 SURVIVORS) IN RELATION TO VENTILATION TIME AND TO SUBGROUPS: WET *a*, WET *b*, AND DRY, ACCORDING TO CONDITION OF AIR PASSAGES PRIOR TO TRACHEOTOMY OR RESPIRATOR TREATMENT

Duration of artificial ventilation	*Wet a*	*Wet b*	*Dry*	Total
None	3	16	8	27
Less than one month	16	13	18	47
One to three months	3	6	13	22
Three to six months	3	7	8	18
More than six months	8	11	13	32
Total	33	53	60	146
% of 146	23%	36%	41%	(100%)
Chronic respirator patients	5	9	11	25

Table XIX compares the presence of secretions in the three groups previously described—*wet a*, *wet b*, and *dry*—in regard to the regression of the respiratory paralysis.

It will be seen that there is no difference whatever between them. In each it was necessary to ventilate about one-third of the patients for more than three months, and in all three groups about one-sixth became chronic respirator patients.

CHRONIC RESPIRATOR PATIENTS

Of the original 345 cases there now remain twenty-five patients wh must be considered chronic respirator patients, requiring artificia ventilation for the rest of their lives Of these twenty-five patients, no less than thirteen require artificial respiration for most of the twenty-four hours, while seven patients are able to do without artificial respiration for a few hours in the daytime, and the rest—five patients—only make use of their respirators during the night, or now and then during meals, and sometimes for a short period after aspiration of secretions

In all of these patients the vital capacity is greatly reduced, usually less than 20 per cent. of normal However, the above-mentioned five patients in this group who require artificial ventilation during the night only, have a vital capacity of 700–1,000 ml, *i.e.*, 20–25 per cent of normal

Of the twenty-five patients twenty-two belong to group C, having pure spinal paralysis of the respiratory muscles, two to group D—with transitory pharyngeal paralysis—and one to group F, who had pharyngeal paralysis as well as 'cerebralia' in the acute phase of the disease

These twenty-five patients are included among the forty-three survivors who still required artificial respiration all round the clock after one month's hospitalization

CHAPTER XII

CONVALESCENT AND CHRONIC STAGE: DECANNULATION AND LATE COMPLICATIONS OF TRACHEOTOMY

BY J FALBE-HANSEN, STEEN JOHNSEN AND J. SCHOU

SOME of the problems which arise in patients who have undergone *tracheotomy* are due directly to the operation and the placing of a cuff-tube or silver cannula in the trachea. These problems may be elucidated best by considering the following questions:

1. What are the indications for the removal of the tracheal cannula?
2. Does a prolonged period of intubation give rise to injury of the trachea?

REMOVAL OF TRACHEAL CANNULA

Decannulation after tracheotomy for laryngismus stridulus or diphtheritic croup is usually easy, as it may be carried out a few days after the operation The problem is different, however, in polio patients in whom a protracted period of intubation is often necessary on account of prolonged respiratory insufficiency. Most of these patients have only weak cough reflexes at the time the tube is removed

Since the cuff-tube is always replaced by a silver cannula as soon as risk of aspiration to the air passages has subsided, decannulation will invariably mean the complete removal of the cannula from the trachea and closing of the operation wound.

There is considerably less resistance to respiration through a silver cannula than is normally present in the larynx and proximal air passages Therefore, decannulation is often followed by slight respiratory distress, on account of the increased dead space. Nearly all these patients are psychically unstable, and as they are particularly apprehensive when the respiratory conditions are altered, they not infrequently tend to aggravate a commencing air hunger. For this reason it is necessary for some time before decannulation to convince the patient that this can be carried through successfully.

Decannulation is out of the question until the patient can do permanently without positive pressure ventilation. On the other hand, the respiratory muscles need not have regained their functional capacity to such an extent that he can breathe by himself both day and night. It is often quite safe to remove the cannula even though the respiration has to be supported by a respirator a few hours daily, for instance by a cuirass respirator or a tank.

The patient must be able to swallow freely, however, before the cannula is removed as otherwise there is a risk of aspiration and obstruction of the air passages As a rule this insufficiency will have subsided by the time the state of the patient otherwise makes decannulation possible.

If the tracheal stoma closes immediately after removal of the cannula, laryngoscopy or bronchoscopy *per os* may become necessary if thereafter the patient cannot keep the airway free Suctioning and lung physiotherapy may also be required So that one condition for decannulation is that the production of secretions in the air passages be negligible, and that the cough be strong enough to bring up the small amount of secretions We removed the cannula only in patients requiring suction at the most, twice a day, and only in those with fairly effective coughing power

The cannula should not be removed before repeated X-ray examination has established that the lungs are clear. If the motility of the diaphragm is lowered considerably—especially in severe unilateral diaphragmatic paralysis—there will be some risk of atelectasis arising in the more poorly ventilated lower parts of the lungs In order to avoid atelectasis after decannulation, the movements of the diaphragm should always be examined fluoroscopically beforehand If they are symmetrical and measure at least three to four centimetres in adults, and two to three centimetres in children, we have found the risk of atelectasis so slight as not to contraindicate decannulation. We have, however, not infrequently decannulated patients with total unilateral paralysis of the diaphragm

Taking into consideration the above-mentioned conditions, we tried to carry through decannulation as early as possible, though efforts were always made to find the optimal time In this connection it is worth mentioning that patients with respiratory poliomyelitis may get into a dangerous condition as a consequence of a mere cold or other intercurrent upper respiratory infection many months after successful removal of the tube Under these circumstances secretions

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Taking into consideration the above-mentioned conditions, we tried to carry through decannulation as early as possible, though efforts were always made to find the optimal time. In this connection it is worth mentioning that patients with respiratory poliomyelitis may get into a dangerous condition as a consequence of a mere cold or other intercurrent upper respiratory infection many months after successful removal of the tube. Under these circumstances secretions

readily accumulate in the air passages, making respiration difficult, and in some cases of this kind it was necessary to readmit the patient in order to support respiration and clear the air passages of secretions. In some few cases tracheotomy had to be repeated.

After removal of the cannula the tracheal stoma usually closed within a couple of days. In some patients, however, who required the cannula for a very long time the edges of the tracheal wound had undergone epithelialization forming a tracheal fistula. In these cases closure of the wound had to be done operatively by circumcision of the surrounding cicatricial tissue, uniting the pretracheal muscles and subcutaneous tissue over the trachea. Finally the skin was sutured with atraumatic material.

In some decannulated patients in whom the tracheal opening closed spontaneously, the scar became retracted and disfiguring, eventually with keloid, so that a plastic operation had to be done for cosmetic reasons.

INJURY TO THE TRACHEA

One would naturally expect that injury to the trachea would occur frequently after protracted positive pressure ventilation. In reality, however, the cuff-tube and the silver cannula have proved to cause only a relatively small number of injuries.

In a little over ten per cent. of the surviving patients, granulation tissue was found in the tracheal stoma and the trachea proper. Invariably such granulations were removed prior to decannulation so as to prevent them from impeding spontaneous respiration.

In thirteen cases the posterior wall of the trachea presented an abrasion a few centimetres beyond the tracheal opening, corresponding to the place where the point of the tube was in contact with the tracheal mucosa. These lesions appeared as necrotic patches more especially when the cuff-tube had been fixed so that its intratracheal part was not in the axis of the trachea. If the cuff-tube was pushed farther down in the trachea this faulty position was corrected, and the abrasion healed spontaneously without further treatment.

In all surviving patients who had had tracheotomy, systematic roentgenography of the trachea was performed in the frontal and in an oblique plane. A little over one-half of these patients were found to show an alteration in the tracheal contour: the lumen

corresponding to the site of tracheotomy had become a little narrower than normal.

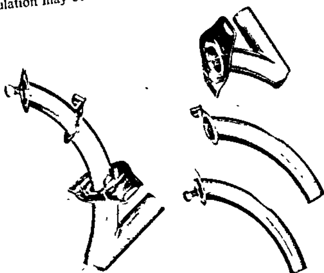
Most often this slight narrowing of the tracheal lumen is of no significance. However, in seven patients—one adult and six children—the radiogram showed, *above* the tracheotomy such a pronounced stenosis as to contraindicate decannulation Severe tracheal stenosis required special treatment but this could not be instituted until positive pressure ventilation was no longer required On the basis of reports in the literature*, and according to our own experience, the following operative procedure was found suitable in cases with severe tracheal stenosis

The operation is done under general anaesthesia and after peroral intubation. At the site of the original tracheotomy an incision is made in the midline, and the entire stenotic part of the trachea is laid free by careful and cautious dissection Scar tissue compressing the tracheal wall from the outside is removed, without injuring the cartilaginous rings of the trachea As far below the original tracheal fenestra as possible, a new tracheotomy is made Generally this means that the new tracheotomy in which a silver cannula is introduced, is done a couple of rings beyond the original incision. The peroral tube is removed, and the anaesthesia is continued through the silver cannula.

The original opening in the trachea is now extended a few millimetres in the midline. After close inspection of the inner aspect of the trachea from the rima glottidis down to the new tracheotomy, and after removal of any granulation tissue present, the wound edges in the trachea are separated so as to permit introduction of a polythene tube. The dimensions of this tube are determined prior to operation as accurately as possible by measuring on the radiogram the lumen of the trachea corresponding to the stenotic area and also the extent of the stenosis. The polythene tube is placed in the stenotic part of the trachea so as to reach from three to eight mm below the rima to the silver cannula. The polythene tube is fixed by means of a silver suture through the cutaneous and muscular layers and through the tracheal wall and the anterior wall of the polythene tube. The skin is united with silk sutures after laryngoscopy has shown that the polythene tube does not protrude through the rima

*Arbuckle (1930), Beal (1930), Cardwell (1946), Erich (1944–45) Figi (1947) Holinger *et al.* (1950), Kretz (1946), Lemariey *et al* (1953), Negus (1938) Preusse (1950), Rapin Schmiegelow (1929) Sercer (1952) Som (1950–51) Suggit (1953).

The polythene tube is left *in situ* for three to five months after which it is removed laryngoscopically. After removal of the silver suture, … to pull it out with forceps. On the following … tuted and when the … ut difficulty to … pletely closed, patient, … breathe from two to four hours … decannulation may be attempted.



CHAPTER XIII

CONVALESCENCE AND CHRONIC STAGE: WEANING PROBLEMS IN ARTIFICIAL VENTILATION

By H. C. A. Lassen

The object of artificial ventilation in a patient with respiratory insufficiency, whether central or spinal in origin, or both, is to tide him over the acute, life-threatening phase of the disease. In the early stage there is still hope that a sufficient number of ganglion cells in the medullary centres and the motor cells of the respiratory muscles will eventually recover, so that the patient will be able to produce enough spontaneous ventilation to become independent of mechanical aid.

Judging from the general impression of a comparatively favourable prognosis in paralysis of the cranial nerves—the lower as well as the upper group—where severe residual paralysis is rather rare one might think that the medullary centres had a similar chance of recovery. Yet, on studying microscopical sections of the reticular formation we often find very extensive damage with disappearance of the great majority of ganglion cells. Such changes are irreparable, and as we never see patients surviving with symptoms attributable to subnormal function of the medullary centres of respiration, i.e., patients with sufficient power of the respiratory muscles to maintain adequate ventilation, but with the irregular type of breathing characteristic of damage to the medullary centres, we must assume that in all patients who regain sufficient muscular power to keep up adequate spontaneous ventilation the respiratory centres are functioning adequately.

On the other hand, all the different respiratory muscles seem to share in the general prognosis of the skeletal muscles, possibly with the exception of the diaphragm. As to the other respiratory muscles, it is usually the rule that the greater the degree of paralysis after the acute stage and the longer it takes before recovery begins the more unfavourable is the prognosis, and the less it can be expected that adequate functional power will ever return. The two halves of the diaphragm, on the other hand, innervated from the third to the fifth cervical segments, do not always seem to follow this pattern, as late

recovery occurs even after four to six months of complete paralysis From a ventilatory standpoint, it is important to stress that unilateral diaphragmatic paralysis is very common in poliomyelitis with respiratory insufficiency.

Naturally, respirator treatment should be of the shortest possible duration, although the patient should not be urged to breathe without mechanical aid at all costs, because then a setback is likely to occur. As usual it is *la juste nuance* that counts, based on intelligent appreciation of the patient's muscular and psychological forces. As the latter cannot be measured, it is here that the temperamental disposition and insight of the doctor in charge comes into the picture It is a good thing for a doctor to be enthusiastic, but it is even better to make the patient enthusiastic, concentrating all his energy on regaining independence of mechanical aid. A great deal can be achieved by painstakingly teaching the patient how best to use the available muscle power, but there is no doubt that in the weaning period inhibiting psychological factors originating from a well understandable neurosis of fear are of considerable importance

A few patients with respiratory insufficiency remain chronic respirator patients because of an unconquerable neurosis based on fear. Most often the patient fears that he will suffocate if he loses consciousness, *i.e.*, if he falls asleep. This is the reason why some chronic respirator patients can be up and about in the daytime but must sleep in the respirator at night. Then again, there are others where the muscular power gives out after a certain length of time, respiration becoming too laboured. If in such patients arterial blood samples are taken while they are out of the respirator, a gradual increase of carbon dioxide tension with eventual lowering of *p*H—respiratory acidosis—can be detected usually long before there is any appreciable lowering of the oxygen saturation. In such cases the need for mechanical aid can be objectively demonstrated. This is not the case in the neurotic type.

Weaning should start as early as possible and first of all by cutting down the help delivered by artificial ventilation. In practice it is our experience that artificial respiration, if the airway is free, very often tends towards hyperventilation. This if moderate is not directly harmful, but should be avoided, because prolonged hyperventilation with low carbon dioxide tension is conducive to increased sensitivity of the respiratory centre. The patient gets used to a low carbon dioxide tension, which makes it more difficult for him to

accustom himself to spontaneous breathing Often a vicious circle is set up which should be avoided.

This can be achieved by reducing the rate of the machine to 10 to 14 per min and especially by decreasing pressures during the inspiratory phase resulting in smaller tidal volumes This avoids hyperventilation.

In this way we can assess the patient's ability to add his own muscular force to the respiratory aid offered by the machine when the ventilatory performance of the respirator at a given setting is known.

If the patient shows signs of returning spontaneous breathing, the next step will be to stop the motor or stop assisted intratracheal ventilation and observe the patient's spontaneous respiratory efforts. This should be repeated [illegible]

[illegible]

beginning it is advisable to measure the blood pressure at short intervals and put the patient back on artificial respiration if the blood pressure rises.

In the majority of cases with respiratory insufficiency recovery will start early The earlier recovery begins, the better is the ultimate prognosis. On the other hand, if a patient must have continuous mechanical ventilation one month after the onset of the disease, his chance of ever regaining complete independence of mechanical respiratory devices is small; in our experience less than ten per cent.

Very often after the first stormy days when the virus infection has burnt itself out and the vascular complications and secondary bacterial infection are under control, recovery proceeds quickly, measurable by increased vital capacity and by the steadily increasing periods of time the patient can be comfortable without mechanical respiratory aid.

Apart from the psychological and biochemical factors, certain other complications may lengthen the weaning period First of all there may be persistent infection in the upper airway, in many cases gradually becoming resistant to all known antibiotics Such intractable infection of the bronchial tree was quite common in our patients and after some time established itself as nosocomial Yet, it only rarely seemed to be the sole cause of death and eventually always cleared up.

These respiratory cripples, those in respirators as well as those leading a precarious life with a greatly reduced vital capacity, very easily become the victims of intercurrent infection of the upper airway often resulting in bronchitis, bronchopneumonia and atelectasis, which may mean a serious, although temporary, setback. All personnel and relatives with even the slightest cold or sore throat should therefore be kept away from these wards and treatment with antibiotics should be prompt. Most of our respiratory invalids were repeatedly immunized against influenza. Children should be vaccinated against whooping-cough and tuberculosis. And any patient with bed-sores should be vaccinated against tetanus.

In some few cases with a tracheotomy, tracheal stenosis developed after several months. This, of course, also made total independence of mechanical aid difficult.

Some twenty-five patients remain who require continuous—and perhaps permanent—mechanical respiratory aid; a few others because of low vital capacities and easily exhaustible muscular power, "frozen" chests or fibrous, nearly immobile diaphragms, are still partly dependent on mechanical respiration Although we continue efforts to get them out of the respirators—and some of them still make small steps forward, for instance by learning frog breathing—our hopes are gradually dwindling. Yet, the patients themselves are remarkably optimistic. They have a tenacious fighting spirit and their morale is excellent. Very few of them ever ask the dreaded question: "Doctor, will I ever get out of this machine?" In my opinion there is hardly ever any need to tell a patient that he will never become independent of the respirator. The full implication of their pitiful condition is realised soon enough.

CHAPTER XIV

LABORATORY CONTROL OF GAS EXCHANGE

BY P ASTRUP

ELIMINATION OF CARBON DIOXIDE

Choice of analytical methods

DURING the poliomyelitis epidemic in 1952 disturbances in the elimination of CO_2 were diagnosed by calculating the arterial (or venous) pCO_2 from a measured value for pH of the blood at 38° C (100 4° F) and a measured value for the total CO_2 content of the plasma

There is no doubt that very accurate results can be obtained in this way Furthermore, this method offers the advantage that determination of pH and the total CO_2 content of plasma allows calculation not only of pCO_2, but also of the bicarbonate content at $pCO_2=40$ mm Hg. (standard bicarbonate) It is practicable, moreover, to determine the oxygen saturation on the same blood sample, and undoubtedly it is an advantage to correlate the results thus obtained with the pCO_2 determinations Frequently a decrease in the oxygen saturation takes place simultaneously with a decrease in pCO_2, indicating development of atelectasis or uneven ventilation of the lungs.

The method is not easy in practice, because each determination requires a sample of arterial blood, and repeated arterial punctures are disagreeable to the patient This drawback, however, can be avoided by insertion of a polythene tube into the brachial artery, under local anaesthesia This may be left *in situ* for up to two weeks, provided the tube is flushed daily with a solution of heparin

Another procedure for estimation of the CO_2 output consists in CO_2 analysis on alveolar air No method yet available has proved entirely satisfactory and all things considered we think that analysis of arterial blood for pH, CO_2, and O_2 constitutes the best and most reliable procedure.

Analytic technique and normal values

A 20 ml glass syringe with glass piston (Summit syringe) is employed. The dead space in the syringe is filled with heparin solution (5 per

cent.). The syringe is warmed beforehand to 38° C. (100 4° F.), and ... after the puncture it is placed in a small thermostatic ... blood at 38° C. (100 4° F.) ... ood, determinations ... ml. of blood (under ... are made of the oxygen satur... paraffin oil) is centrifuged to obtain plasma for determination of the total CO_2 content.

Estimation of *p*H

We have chosen to estimate *p*H of the blood directly on the heparinized blood at 38° C. (100 4° F.), and this determination must be performed immediately after taking the blood sample, so as to avoid a fall in *p*H due to glycolysis. The effect of glycolysis has not been demonstrable within thirty minutes and in every case we have measured *p*H within fifteen minutes after the puncture. Measuring of *p*H may be postponed for up to 24 hours, if glycolysis is prevented by addition of sodium fluoride (Craig *et al.*, 1952). The actual measurement is performed in the incubator at 38° C. (100 4° F.), in which the electrodes, buffer solution, rinsing water and sodium chloride solution are left standing constantly.* The *p*H meter remains outside of the incubator.

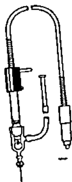


FIG 43 Glass electrode (Radiometer m G 263)

The buffer solution is prepared from 200 ml M/15 primary potassium phosphate (9 078 g. dry KH_2PO_4 per litre) and 800 ml M/15 secondary sodium phosphate (11·8667 g $Na_2HPO_4,2H_2O$ per litre) The *p*H of this solution at 38° C. (100 4° F.) is 7·35 (Astrup, 1954)

Before the measuring of *p*H the electrode chamber is first rinsed a few times in distilled water, then with the buffer solution. The electrodes are immersed in the saturated potassium chloride solution, and the apparatus adjusted to the *p*H of the buffer solution. After this the chamber of the electrode is rinsed four times with distilled

* The measuring apparatus used by us was manufactured by Radiometer, Copenhagen, *p*H-meter type PHM 3 The electrodes were also supplied by Radiometer, calomel electrode No K 301 and glass electrode No G 263 with red inner fluid Above the bulb of the electrode a small chamber may be attached, enclosing the bulb (see Fig 43) so that the fluid may be sucked up round the electrode This electrode was highly stable but required adjustment of the *p*H scales five entire *p*H units below the measured value Thus, if the buffer solution had to equal *p*H 7 35, the buffer adjustment was set at 2 35. In measuring blood the *p*H scale was altered until the zero position was reached. When the scale showed a value of 2 57, the real *p*H value for blood was 7 57

water and then filled with blood and the measurement made The blood is taken from a small tube, in which it stands covered by a layer of paraffin oil, to which it was transferred directly from the warm syringe After this first measurement the procedure is repeated with washing of the electrode, adjustment of the apparatus to the *p*H of the buffer, and repeated measuring of the *p*H of the blood sample. It occasionally happens that two measurements of the same blood sample differ by more than 0 01 *p*H unit but this is very unusual and the technique is remarkably reliable. Measuring of *p*H with duplicate determinations can be performed within four to five minutes

Determination of total plasma CO_2

This is carried out in the usual way with Van Slyke's manometric apparatus

NORMAL VALUES

In twenty-eight normal men and women the following values were found in *venous blood* (taken from a cubital vein without stasis)

*p*H	7 34–7 43
pCO_2	40–53 mm Hg
Total CO_2 in plasma	23 7–31 2 mMol 1
Bicarbonate at pCO_2=40 mm. Hg.	24 8$\pm$2 5 mMol. 1

In *arterial blood* the normal values are·

*p*H	7 38–7 47
pCO_2	35–43 mm Hg
Bicarbonate at pCO_2=40 mm. Hg	22·3$\pm$2 5 mMol 1

Variations of the blood *p*H, pCO_2 and total CO_2 content in polio patients

During the first five months of the poliomyelitis epidemic we performed altogether 705 determinations of *p*H in arterial or venous blood from [illegible]

normal level, in arterial blood between 25 and 35, in venous blood between 30 and 40 mm. Hg. The lowest value found for *p*H was 6·99

in venous blood, the highest 7·86 in arterial blood. The highest pCO_2 found was 150 mm. Hg. in venous blood, the lowest 9 mm. Hg in arterial blood. On the whole, then, most of the patients were slightly alkalotic with lowered pCO_2, and this was the rule in patients given manual positive pressure ventilation.

TABLE XX

pH AND pCO_2 IN ARTERIAL AND VENOUS BLOOD IN PATIENTS WITH RESPIRATORY INSUFFICIENCY

pH IN ARTERIAL AND VENOUS BLOOD

*p*H	6 95	7.00	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	60	.65	.70	.75	.80	85	.90
a		0	0	1	2	4	5	4	20	52	71	88	70	43	18	10	6	2	0	1
v		1	0	0	2	4	2	10	24	48	81	63	35	23	11	2	2	0	0	0

CO_2-TENSION IN MM. HG.

	<10	10	15	20	25	30	35	40	45	50	55	60	65	70	>70	Total
a	1	2	31	45	68	74	39	41	15	14	5	5	4		6	350
v	0	0	10	19	23	60	46	53	29	21	7	10	1		8	287

a = arterial blood v = venous blood

It was a striking observation that, within a relatively short period, the same patient might show enormous changes in pH, total CO_2 content of the plasma and pCO_2—as is evident from Table XXI which shows some measurements obtained in a five-year-old boy, who on

TABLE XXI

EXAMPLE OF RAPID CHANGES IN BLOOD pH, pCO_2 AND TOTAL CO_2 CONTENT OF PLASMA

J P G., boy, age 5

Date	Hour	a/v	pH	Total CO_2 (mMol)	Free CO_2 (mmHg)	HCO_3^- (mMol)
	11.40	v	6 99	39 0	150	34 5
6 9	14 10	a	7 52	24 4	32	24·5
	15 05	a	7·65	15 6	14	15 2

a = arterial blood v = venous blood

admission was exceedingly ill, practically moribund In the venous blood *p*H was 6·99, the total carbon dioxide content of plasma 39 mMol/l and pCO_2 was 150 mm Hg After tracheotomy and institution of manual positive pressure ventilation *p*H in arterial blood rose within three hours to 7 52, and about one hour later to 7 65, accompanied by a fall in the total CO_2 content of plasma as well as in pCO_2

Similar pronounced changes have also been observed in some other patients.

On the other hand, patients in a relatively constant clinical condition showed surprisingly slight variations in *p*H and pCO_2 from one day to another, as will be noticed from Table XXII

TABLE XXII

VARIATIONS IN BLOOD *p*H, pCO_2 AND TOTAL CO_2 CONTENT OF PLASMA IN A PATIENT IN A RELATIVELY STABLE CLINICAL CONDITION

I B I, woman, age 30

Date	Hour	a v	*p*H	Total CO_2 (*mMol*)	Free CO_2 (*mmHg*)	HCO_3 (mMol)
1/9	13 00	v	7 49	24 0	32	24 1
	16 45	v	7 47	22 2	31	21 3
2/9	9 15	v	7 50	25 0	32	24 2
	10 30	a	7 50	25 6	36	24 5
	10 35	v	7 47	24 8	34	28 8
	14 15	v	7 48	26 3	36	25 2
4/9	9 10	v	7 55	26 7	30	25 8
6/9	10 55	a	7 55	26 2	30	25 3
8/9	12.35	v	7 56	27 6	31	26 7
10/9	10 10	v	7 70	22 1	17	21 6
13/9	10 10	v	7 56	21 0	23	20 3

a = arterial blood v venous blood

In this patient continued measurements presented the following interesting observations

On September 9 it had been decided to increase the rate of manual ventilation in all the patients from 20 to 30. On the following day the *p*H was found to be 7·70, and the pCO_2 value was 17. Corresponding shifts in these values were found in all the patients on that day, after which it was decided to lower the rate to 25. This patient then showed a fall in *p*H to 7·56 and a rise in pCO_2 to 23.

Our measurements afforded strong proof that it is absolutely impossible from the total CO_2 content of plasma (by many authors designated as bicarbonate) alone to decide whether a given patient is alkalotic or acidotic—which again means whether *p*H is increased or lowered. The situation becomes particularly complicated if the respiratory disturbances are also associated with disturbances in the acid-base metabolism—as is clearly evident from the well-known Henderson-Hasselbalch equation.

$$pH = pK + \log \frac{HCO_3^-}{H_2CO_3}$$

which signifies that *p*H is dependent upon the ratio between the chemically bound CO_2 (numerator) and the physically bound CO_2 (denominator) not upon the sum of them, which is determined by manometric or volumetric methods.

Fig. 44 shows that with blood $pH = 7{\cdot}42$ total carbon dioxide values may vary from 15 to 30 mMol./l, and that a total CO_2 content of 20 mMol /l has been found in blood with *p*H varying between 7·35 and 7 70.

Probably the patients here included had no form of metabolic disturbance in their acid-base metabolism. In contrast, such metabolic disturbances were present at any rate in some of the patients whose analytical values form the basis for Fig 45. The nonprotein nitrogen in all of these patients was over 100 mg per cent., so that presumably a more or less pronounced renal acidosis was present. It will be noticed that these values show a wider scatter than in Fig 44, and that there is no relation between the total CO_2 content of plasma and *p*H of the blood.

In order to ascertain the extent of the metabolic disturbances in such cases, it is necessary to determine the amount of bicarbonate at $pCO_2 = 40$ mm. Hg, which can be calculated from the values measured for blood *p*H and total CO_2 content of plasma (Astrup, 1954, Astrup, Gøtzsche and Neukirch, 1954)

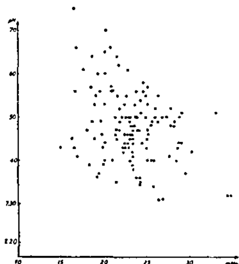


Fig 44

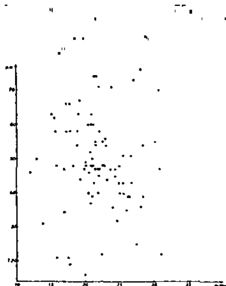


Fig 45

Relation between blood *p*H and total CO_2 content of plasma in patients with respiratory insufficiency and more than 100 mg per cent NPN in the arterial blood

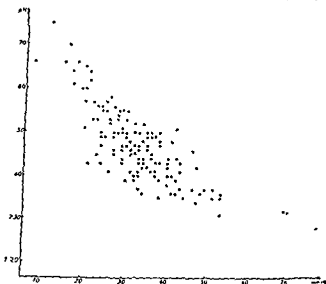


Fig. 46

Relation between blood pH and pCO_2 in patients with respiratory insufficiency and no demonstrable metabolic disturbances of the metabolic acid-base equilibrium

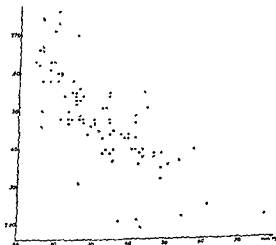


Fig 47

Relation between blood pH and pCO_2 in patients with respiratory insufficiency and with more than 100 mg per cent NPN in the arterial blood

Fig. 46 shows the correlation of pH and pCO_2 in patients with less than 70 mg. per cent. of nonprotein N It will be noted that the correlation between these values is fairly good. It is considerably less pronounced in patients with a nonprotein N over 100 mg. per cent. (Fig. 47) where, besides the respiratory disturbances in the acid-base metabolism, there were also metabolic disturbances As will be noted, a low pH may very well be associated with a normal carbon dioxide tension as evidence of adequate ventilation.

OXYGEN ABSORPTION

The oxygen absorption is controlled by determination of the oxygen saturation in arterial blood

The apparatus here employed was a haemoreflector manufactured by Kipp, Holland, according to the principle given by Brinkmann (Zijlstra, 1951) By always making sure of the value for 100 per cent saturation of the blood employed, very constant values were obtained with this apparatus The analysis takes only four to five minutes

The normal values for oxygen saturation in arterial blood are 93–98 per cent.

Determinations of the oxygen saturation in arterial blood in patients with respiratory insufficiency prior to treatment show that decreased oxygen saturation is common, and that it is this oxygen deficit which causes the sensation of air hunger, as this symptom may be ameliorated by increasing the oxygen intake without increasing the ventilation Altogether twenty-five patients with respiratory insufficiency were examined prior to treatment, and in these cases the oxygen saturation was found to vary between 80 and 96 per cent It is to be stressed that in cases with decreased oxygen saturation there were invariably clinical signs of pronounced respiratory insufficiency constituting an absolute indication for artificial respiration of some kind So measurements of oxygen saturation are usually of minor importance as an indication for artificial respiration.

When the patient is in a respirator a decrease in oxygen saturation may occur also as a consequence of atelectasis or of uneven gas exchange—and this is perhaps the field in which determination of the oxygen saturation is of greatest importance. It s emphasized that lowered oxygen saturation may

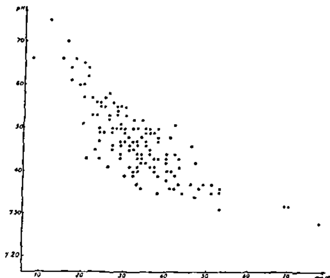


FIG 46

Relation between blood *pH* and *p*CO_2 in patients with respiratory insufficiency and no demonstrable metabolic disturbances of the metabolic acid-base equilibrium

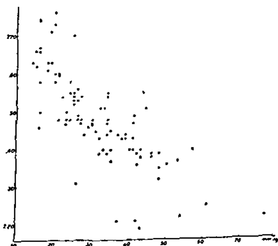


FIG. 47

Relation between blood *p*H and *p*CO_2 in patients with respiratory insufficiency and with more than 100 mg per cent NPN in the arterial blood

Fig. 46 shows the correlation of pH and pCO_2 in patients with less than 70 mg. per cent of nonprotein N. It will be noted that the correlation between these values is fairly good. It is considerably less pronounced in patients with a nonprotein N over 100 mg per cent. (Fig. 47) where, besides the respiratory disturbances in the acid-base metabolism, there were also metabolic disturbances. As will be noted, a low pH may very well be associated with a normal carbon dioxide tension as evidence of adequate ventilation.

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overelimination of CO_2, from the well-ventilated areas of the lungs —a condition we have encountered a great number of times

It would be interesting also to determine the oxygen tension, but we had no suitable technique available for this. Lowered oxygen tension in the tissues may occur not only in cases with decreased oxygen saturation in the blood, but also in markedly alkalotic patients with normal oxygen saturation, as the dissociation curve for oxyhaemoglobin is shifted to the left, so that oxygen can be given off peripherally only at an abnormally low oxygen tension. When patients under positive pressure ventilation not infrequently complain of air hunger, this may perhaps be connected with the respiratory centre getting accustomed to a high pH and a low CO_2 tension in the blood reacting to a more or less sudden shift to the acid side. If thus a normal individual is made to hyperventilate for twenty-four hours in a respirator, he will continue hyperventilating for up to twelve hours after—until the reactivity of the respiratory centre again becomes normal. Similarly, we explain the cyanosis not infrequently observed under hyperventilation—in spite of normal oxygen saturation in the arterial blood—as attributable to lowered oxygen tension in the tissues resulting from the effect of alkalosis upon the dissociation curve of oxyhaemoglobin combined with decreased blood flow as a consequence of shock or local vasospasm. The latter phenomenon is known to be produced by low CO_2 tension (Rice, 1950).

CHAPTER XV

LABORATORY FINDINGS

By P. Astrup, T Bennike and L. Grandjean

Patients with respiratory failure present a number of deviations from normal biochemical and physiological conditions, ascribable partly to the disease itself and partly to the effect of artificial respiration, in particular on the circulation.

GAS EXCHANGE IN THE LUNGS

The laboratory control of the gas exchange was carried out by determination of pCO_2 in arterial or, sometimes, venous blood together with determination of the O_2 saturation in arterial blood. This technique is described in Chapter XIV.

SHOCK

Haemoconcentration can be demonstrated most readily by repeated haemoglobin determinations. These were performed frequently—from four to six times daily—by determination of the haemoglobin content of ear-blood.

KIDNEY FUNCTION

The NPN concentration in the blood was determined regularly, often daily (microtechnique on ear-blood). In a majority of patients with respiratory insufficiency there appeared even in the first days of illness a rise in the NPN concentration, in 105 patients exceeding 70 mg. per cent. In no less than fifty-three cases the rise exceeded 100 mg. per cent., and in some of the latter uraemia developed and terminated fatally. This rise in NPN, we think, was ascribable to a temporary or, in some cases, permanent impairment of the kidney function from a state of shock combined with an increased excretion of nitrogenous substances as a consequence of the marked tissue disintegration.

LIVER FUNCTION AND SERUM PROTEINS

Fractional determination of serum protein was performed not infrequently in the course of the disease in 180 patients, in 100 of whom it was supplemented by repeated liver function tests.

On summing-up our findings it may be said that a fall in serum albumin was an almost constant phenomenon in the acute phase of the disease (Fig 48) primarily related to the presence of respiratory paralysis and in a lesser degree to the extent of the other pareses.

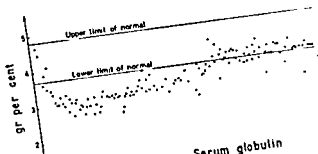
In the patients with reduced ventilation, liver function tests showed a picture similar to that encountered in decompensated cardiac disease, with vascular stasis in the portal circulation, particularly characterized by a positive bromsulphalein test. The urobilin and serum-bilirubin tests were less frequently positive. These findings were far from infrequent in patients with spontaneous respiration.

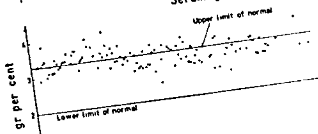
The highest frequency of abnormal liver function tests was observed in the group with the lowest values for serum albumin It seems most natural, we think, to attribute this correlation to the debility of the patients and their severe respiratory insufficiency, resulting in a decrease of the blood flow in the liver, possibly accentuated by the use of positive pressure ventilation, which constituted the standard therapy in these cases

Clinical jaundice of slight and transitory character was observed in twelve patients, in most of whom it appeared within the first month of illness In two patients, however, jaundice did not appear until the fourth and sixth month of illness respectively, and here it was accompanied by clinical and biochemical signs of hepatitis. In these two cases the possibility of serum hepatitis cannot be excluded.

NITROGEN METABOLISM

We followed the twenty-four hour output of nitrogen through a considerable length of time in fourteen patients with severe paralysis. A few days after onset of paralysis, the nitrogen output began to rise, reaching a maximum in the second week at which time the twenty-four hour output of nitrogen amounted to 45 g After this the output fell and returned to a normal level in the third or fourth week.





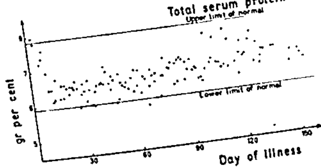


FIG 43

Average daily serum protein values in forty poliomyelitis patients with severe respiratory insufficiency followed through five months

In twelve paralytic patients the urine was tested by paper chromatography with regard to the presence of amino acids. No definite pathological conditions were found, either qualitatively or quantitatively. However, five of these patients, with severe paralysis, showed an increased output of taurine, which presumably is attributable to increased tissue *disintegration*.

In nineteen patients the concentration of amino acid nitrogen in serum was found to be between 5·3 and 10 4 mg. per cent. Using the same technique eleven normal individuals showed concentrations of 5·5–9·8 mg. per cent. Thus no abnormality was demonstrated in this respect.

POTASSIUM

In a considerable number of patients the serum potassium concentration was determined repeatedly. In a majority the values were normal, but in a few cases we found hypopotassaemia, calling for parenteral administration of potassium Hyperpotassaemia was found in some patients with azotaemia.

The increased nitrogen output in the urine runs parallel with an increased excretion of potassium, often to more than three times the normal, attributable to liberation of potassium in the paralyzed muscles.

SODIUM CHLORIDE

The concentrations of sodium and chlorides in serum were usually normal, sometimes subnormal. The sodium chloride balance was followed by daily estimation of urinary chlorides by a simple bedside test (Fantus test). We tried to control the intake of salt so that the twenty-four hour urine specimen contained only a few grams of sodium chloride per litre Overdosage of sodium chloride is dangerous and in the early part of the epidemic it gave rise to some cases of pulmonary oedema

The fluid-balance was followed closely by recording the fluid intake and output on special charts.

CALCIUM

In many patients in the acute stage the calcium content of serum stayed within normal limits.

The calcium excretion in the urine was not followed in the acute stage. As is well-known, however, there is a considerable physiological loss of calcium in the first period of illness, brought about by the confinement to bed and the paralysis. The significance of this in the formation of renal calculi, which occurred in twenty patients, is mentioned in Chapter XVII.

HAEMORRHAGIC DIATHESIS

About 130 patients had signs of haemorrhagic diathesis and were examined in this respect. Some of them showed a true increase in tendency to bleeding The examination included estimation of prothrombin and fibrinogen, coagulation time, bleeding time and capillary resistance

Except for a few patients showing a moderately decreased prothrombin content of the plasma, all the findings proved normal apart from the capillary resistance. There was a distinct correlation between lowered capillary resistance and the bleeding tendency We do not know the reason for this decrease in capillary resistance Anoxaemia undoubtedly is not the decisive factor even though it perhaps may be contributory. It seems more plausible to refer the haemorrhagic diathesis to changes in the vegetative nervous system, perhaps especially in the hypothalamus (*cf* Baker *et al*, 1952) The slow regression of the capillary anomaly in poliomyelitis patients—as a rule lasting several months—as compared to the far more rapid regression observed in patients with lowered resistance following narcotic poisoning points in the same direction

This brief survey of the more important biochemical disturbances shows that patients with respiratory insufficiency may present very complicated clinical pictures, which laboratory examinations may help to elucidate. For the daily control of the patients it is of particular importance to estimate the blood pH and pCO_2, haemoglobin and NPN concentrations in the blood, potassium content of plasma and chloride excretion with the urine

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HAEMORRHAGIC DIATHESIS

About 130 patients had signs of haemorrhagic diathesis and were examined in this respect. Some of them showed a true increase in tendency to bleeding The examination included estimation of prothrombin and fibrinogen, coagulation time, bleeding time and capillary resistance

Except for a few patients showing a moderately decreased prothrombin content of the plasma, all the findings proved normal apart from the capillary resistance There was a distinct correlation between lowered capillary resistance and the bleeding tendency We do not know the reason for this decrease in capillary resistance Anoxaemia undoubtedly is not the decisive factor even though it perhaps may be contributory It seems more plausible to refer the haemorrhagic diathesis to changes in the vegetative nervous system, perhaps especially in the hypothalamus (*cf* Baker *et al*, 1952) The slow regression of the capillary anomaly in poliomyelitis patients—as a rule lasting several months—as compared to the far more rapid regression observed in patients with lowered resistance following narcotic poisoning points in the same direction

This brief survey of the more important biochemical disturbances shows that patients with respiratory insufficiency may present very complicated clinical pictures, which laboratory examinations may help to elucidate For the daily control of the patients it is of particular importance to estimate the blood *p*H and pCO_2, haemoglobin and NPN concentrations in the blood, potassium content of plasma and chloride excretion with the urine

CHAPTER XVI

ELECTROCARDIOGRAPHIC CHANGES IN ACUTE POLIOMYELITIS

By Kai Bjerre-Christensen

It has long been recognized that the poliomyelitis group of viruses is not strictly neurotropic, and with the recent demonstration of a viraemic phase in the incubation period of poliomyelitis the widespread occurrence of histological changes outside the central nervous system presents no problem.

Myocardial changes in poliomyelitis were already reported by Robertson and Chesley (1910). A proper evaluation of the histological findings was, however, not possible until Saphir and Wile (1942) described acute myocarditis in six of seven patients who died of poliomyelitis.

The literature on the histological myocardial changes was reviewed by Dolgopol and Cragan (1948), and a survey, including the electrocardiographic changes too, has been given by Weinstein and Shelokov (1951). In the paper of Joos and Yu (1950) references are given to general surveys of the cardiovascular manifestations in poliomyelitis and other viral diseases.

Recent studies have extended our knowledge of the nature and significance of the electrocardiographic changes,* yet some problems of the cardiac involvement in poliomyelitis are still incompletely elucidated.

MATERIAL AND METHODS

A description of the total series of 345 patients with life-threatening poliomyelitis is given in Chapter II (p 5). Electrocardiograms are available in 197 cases, these cases do not represent a deliberate selection of the total series, but were chosen at random in an attempt to have all patients examined Only records made in the acute stage of the disease are considered, *i.e.*, electrocardiograms taken within three weeks from the onset of the meningeal stage.

* Donhardt (1953), Fox *et al* (1953), Georg *et al* (1953)

Statistically these 197 patients are not quite representative of the total series, a certain unintentional selection being manifest by the fact that 131 patients of 201 survivors were examined (65 per cent) as compared with sixty-six of 144 fatal cases (46 per cent.). The main reason for this uneven representation is that a total of twenty-three patients died shortly after—or within twenty-four hours of—admission, the majority before an electrocardiogram had been recorded Nevertheless the number of tracings in fatal cases exceeds that in other series published.

Clinically, however, the selected series does not deviate from the total series The disease progressed in a similar way in many patients admitted in less advanced stages, and in whom electrocardiograms were taken, as in those who died within twenty-four hours of admission In the two groups the autopsy findings were in accord

Electrocardiograms were taken shortly after admission and subsequently at varying intervals, most often once a week In some patients electrocardiograms were recorded serially for a longer or shorter period The total number of records exceeds 1000. A portable amplifier-electrocardiograph was used, and the three bipolar standard limb leads were recorded simultaneously In a few instances the precordial leads CF_2 and IV F were included but proved of no further value, accordingly only the limb leads will be considered.

The criteria of interpretation were essentially those given by Katz (1946). As upper limits for the Q–T interval we used the values given by Ashman and Hull (1941) corrected for heart rate and age. The electrical axis of the ventricular complex was estimated according to the diagram set up by Warburg (1943), and in cases of right or left axis shift, the axis was computed

In adults the normal limits of the QRS axis are stated as 0° to +90° (Warburg, 1946) Since most electrical axes in this series ranged between +60° to +90°, and since the series included many children with an axis more to the right, electrocardiograms with axes between +90° and +100° were considered normal, provided that the axis shift was not associated with T-wave changes of the strain type White (1947) states the range of the normal electrical axis as −20° to +100°.

A deflection of 10 mm in the tracings published equals an E M F. of 1 mV; as regards the time-marking the distance between two narrow lines is 0 02 seconds, between two wide lines 0 1 second

RESULTS

A preliminary analysis of the series showed that sinus tachycardia, disproportionate to fever, occurred in eighty-six of the 197 patients (44 per cent.). In forty-six cases the tachycardia exceeded 140/min., in the remaining forty cases 120/min. In four patients the heart rate was above 200/min. Tachycardia was of equal occurrence in living and fatal cases, *viz.* in fifty-six of 131 living (43 per cent.), and in thirty of sixty-six fatal cases (45 per cent.).

A classification of the electrocardiograms in normal and abnormal tracings, irrespective of tachycardia, disclosed that forty-eight of ninety-nine abnormal, and thirty-nine of ninety-eight normal tracings showed sinus tachycardia. The more frequent occurrence in the former group is not unequivocal, because some of the abnormal tracings show an isolated RS–T segment depression which may be secondary to the tachycardia (*cf.* Table XXVI)

In order to facilitate comparison of other publications with the present series the frequency and distribution of tachycardia have been mentioned. Obviously the tachycardia was due to multiple and non-cardiac causes, and no inference could be drawn as to the condition of the myocardium In the subdivision of the electrocardiograms into normal and abnormal tracings no account has been taken of the occurrence of tachycardia. Sinus arrhythmia of the respiratory variety, was observed in a non-specified number of patients.

The series includes 180 children and 165 adults; about three-fifths were males and two-fifths females.

TABLE XXIII

DISTRIBUTION OF 197 ELECTROCARDIOGRAMS IN 345 CASES OF POLIOMYELITIS ACCORDING TO AGE AND SEX

	AGE		SEX	
	children	adults	male	female
Number of cases	180	165	196	149
Number of ECG's	81	116	110	87
Percentage of ECG's	45	70	56	58

Equal proportions of males and females were examined, but electrocardiograms were recorded more frequently in adults than in children (70 per cent as compared to 45 per cent) The reason for this difference is not evident but difficulties in obtaining suitable tracings in young children may have been of some importance.

The incidence of abnormal electrocardiograms is almost the same in adults and in children, *viz* 53 per cent. (61 of 116) and 47 per cent (38 of 81), respectively

Because of the limited size of the series the percentage of abnormal tracings cannot be correlated with the death rate in the individual sub-groups The incidence of abnormal curves, however, increases with the severity of the disease as recorded in Table XXIV which shows the mortality and frequency of abnormal electrocardiograms in the three sub-groups A+B, C+D and E+F (*cf* p 8)

TABLE XXIV

DISTRIBUTION OF 142 FATAL CASES AND 99 ABNORMAL ELECTROCARDIOGRAMS IN SUBGROUPS OF THE TOTAL SERIES OF CASES

Subgroups of total series	Fatal cases		Abnormal ECG's	
	number	percentage	number	percentage
A+B (87 cases)	32	39	20	23
C+D (185 cases)	61	33	50	27
E+F (73 cases)	49	67	29	40

Within the individual sub-groups abnormal tracings are equally common in living and fatal cases, and the parallelism between the incidence of abnormal records and mortality does not indicate a causal relationship A similar distribution applies *e g* to the incidence of pulmonary complications (36, 65 and 77 per cent respectively)

This preliminary analysis then showed no relation between the occurrence of abnormal electrocardiograms and the age and sex of the patients, but an increase of frequency with the severity of the disease In the subsequent analysis advantage will be taken of the large number of electrocardiograms in fatal cases, which makes possible a comparison of the findings in deceased and surviving patients.

Table XXV shows the distribution of normal and abnormal electrocardiograms according to final outcome.

In addition to sixty tracings conforming to the accepted standards the group of normal electrocardiograms includes twenty-eight records showing sinus tachycardia (disproportionate to the temperature) and ten records with tachycardia and a right axis shift within the limits of +90° to +100°.

The total incidence of abnormal electrocardiograms was fifty per cent and in Table XXVI the changes in ninety-nine patients with abnormal tracings are recorded. The number of abnormalities was higher as more than one simultaneous deviation was observed in most patients

Abnormalities were almost equally frequent in survivors and fatal cases, and it is apparent that widely different changes are represented, and that no individual finding can be suggestive of a specific poliomyelitic involvement of the heart.

Only the first seven items in Table XXVI, a total of twenty abnormalities representing disturbances in the initiation and conduction of the impulse in the auricular and junctional tissues, have a correlation with the mortality in that sixteen of these abnormalities were found in the forty-two fatal cases and only four in the fifty-seven survivors The majority of the electrocardiographic findings indicate disturbances in the resting, depolarized state of the heart or in the repolarization mechanism, and have no prognostic significance.

P-wave changes. tall, peaked or rounded, P-waves exceeding 0 25 mV occurred in seven cases; inverted P-waves in two leads were observed twice. Tall P-waves were more frequent than usual and often accompanied by tachycardia and/or right axis shift or right heart strain.

The cases of auricular flutter, atrio-ventricular block, premature contractions, bundle branch block, low voltage, and the Q_1T_1 pattern probably indicate organic myocardial damage, which may account for the associated serious prognosis.

A Q_3T_3 pattern was encountered in eight patients, five of whom were children under six; in all eight cases pulmonary atelectases were present. Posterior myocardial infarction could be excluded by serial electrocardiography

Depression of the RS–T segment was most common in the second and third leads but could be found in all three leads. Tachycardia and T-wave changes were frequently associated findings.

TABLE XXV

RELATIVE DISTRIBUTION OF ABNORMAL AND NORMAL ELECTROCARDIOGRAMS ACCORDING TO FINAL OUTCOME

	Number of cases		
	Total	Living	Dead
	345	203	142
Total number of electrocardiograms	197	131	66
Abnormal tracings	99	57	42
Normal tracings	98	74	24
Abnormal tracings in percentage of total number of ECG's	50	44	63

TABLE XXVI

INCIDENCE AND DISTRIBUTION OF ELECTROCARDIOGRAPHIC CHANGES IN 57 LIVING AND 42 DEAD CASES

Abnormalities	Number of cases	
	Living 57	Dead 42
P-wave changes	3	6
Atrial flutter	—	1
P–Q interval, prolongation of		
Complete A–V block	—	1
Incomplete A–V block	—	1
Premature contractions (supraventricular)	—	3
Bundle branch block	1	2
Low voltage	—	1
Q_1T_1 pattern	—	1
Left axis shift	1	1
Q_3T_3 pattern	5	3
Right heart strain	10	6
RS–T segment, depression of		
Combined with tachycardia	15	9
Without tachycardia	11	7
T-wave changes	25	14
Q–T interval, prolongation of	20	14
	91	70
Tachycardia in combination with changes other than axis shift and RS–T segment depression	(8)	(2)

T-wave changes occurred in thirty-nine patients, generally as inverted, diphasic, or isoelectric T-waves in one or more leads. A few cases showed huge, peaked T-waves in the second and third leads (Fig. 49). In the majority of cases the T-wave changes were of the primary type.

Prolongation of the Q–T interval was observed in 34 cases, and was actually due to an increase in the duration of the RS–T interval, whereas the initial complex remained unchanged.

RS–T segment depression, T-wave changes and prolongation of the Q–T interval represented 115 of the 161 abnormalities (72 per cent) These changes had no relation to mortality; they were often transitory, fully reversible, and showed marked day-to-day variations.

A right heart strain pattern (right ventricular strain) occurred in sixteen patients and represented a distinctive element of the series—possibly together with the Q_3T_3 pattern—because in all cases it could be correlated with the occurrence of a pulmonary atelectasis (Fig 50). The electrocardiographic changes were evident shortly after development of the atelectasis. Ordinary pneumonic infiltrations did not cause similar changes.

In the present study massive and protracted atelectases were diagnosed in sixty-eight patients, whereas a right heart strain pattern was observed in only sixteen cases. In most of the remaining cases a relative shift to the right of the QRS axis coincided with the development of atelectasis; conversely a shift of the axis to the left could be seen with subsidence of the atelectasis.

INTERRELATION OF ELECTROCARDIOGRAPHIC AND HISTOLOGICAL FINDINGS

The autopsy findings in 115 of the 144 fatal cases of the total series are discussed in Chapter XIX (p. 151). Of the sixty-six fatal cases included in the electrocardiographic series only forty-six form part of the autopsy material, and the subsequent discussion will apply only to these forty-six cases.

As stated above, no single electrocardiographic abnormality is suggestive of a poliomyelitic myocarditis, and most changes did not influence prognosis at all. Attempts at correlating certain electrocardiographic and histological findings would of necessity involve



FIG 49

Three tracings from a series in a five-year-old boy intended to demonstrate rapid and *pronounced T-wave changes with only slight* QRS *complex variations* *The* significance of the huge T-waves in the second and third limb leads was not ascertained

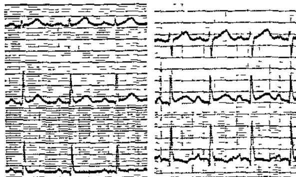


FIG 50

Development of right heart strain pattern coincident with origin of pulmonary atelectasis Note associated rise in heart rate

electrocardiographic changes unrelated to mortality, and accordingly be of little value.

Nevertheless, various electrocardiographic pictures might be representative of poliomyelitic myocardial lesions, as suggested by (1) the early occurrence in patients of electrocardiographic changes for which no other aetiological factors could be recognized, and (2) the prognostic significance of a few changes indicating disturbances in impulse generation and conduction.

In a number of cases with definitely abnormal electrocardiograms, however, a scrutiny of the myocardial sections revealed significant changes in less than half the number of cases, and no better results were achieved when definitely abnormal myocardial sections were compared with the corresponding electrocardiograms.

It must be concluded that in this study, no interrelation of the electrocardiographic and histological findings could be demonstrated This conclusion does not exclude a specific poliomyelitic involvement of the heart, but rather emphasizes the fact that, notwithstanding a specific aetiology, the histological and electrocardiographic pictures will also be determined by the anatomical and functional reactivity of the myocardium.

The occurrence of a right heart strain pattern in the present series of acute cases, could not be correlated with the autopsy findings However, reference should be made to the fact that in thirty-four autopsied cases dilatation of the right ventricle was evident, and that extensive atelectases occurred in about fifty cases.

DISCUSSION

The incidence of electrocardiographic changes in this series (50 per cent.) is somewhat higher than that usually stated (*cf.* Table XXVII which records values between 13 per cent. and 77 per cent., with an average of 35–40 per cent.)

Differing criteria of interpretation represent a basic cause for the differences, but the deliberate inclusion or omission of certain findings is of additional importance. Tachycardia is included in the paper by Manning and Yu (1951), but is not reported by Bradford and Anderson (1950) Donhardt (1953) does not include electrocardiographic changes due to " eindeutig hypoxämische Zustande."

The number of electrocardiographic leads and the frequency of recording may also affect the results. Besides the standard limb leads most authors employ three (augmented) unipolar limb leads and six precordial V-leads.

TABLE XXVII

NUMBERS AND PERCENTAGE OF ABNORMAL ELECTROCARDIOGRAMS IN SOME PUBLISHED SERIES

AUTHOR(S)	Total no of cases	Abnormal ECG's	
		numbers	percentage
Gefter *et al* (1947)	226	32	14
Bradford & Anderson (1950)	155	20	13
Frischknecht & Zellweger (1950)	52	21	40
Joos & Yu (1950)	23	11	48
Laake (1951)	165	84	32
Manning & Yu (1951)	150	116	77
Weinstein & Shelokov (1951)	85	25	29
Donhardt (1953)	472	205	44
Fox *et al.* (1953)	189	61	32
Georg *et al.* (1953)	62	14	23

The possible influence of varying cardiotropism of different strains of poliomyelitis virus has been mentioned by several authors, *e g* Fox *et al.* (1953) and Georg *et al* (1953) An appraisal of this point is difficult, Weinstein and Shelokov (1951) and Laake (1951) found only " insignificant differences " in various epidemics In an autopsy series of forty-seven cases Teloh (1953) noted unusually severe myocardial changes in one of the ten years covered Even provided that the diagnostic criteria were uniform in the above examples, the series were small and aetiologic factors, other than viral involvement, may explain the differences

There [illegible]

quency of abnormal tracings unrelated to the intensity or type of infection, most authors agree that the percentage of abnormalities increases with the severity, extent, or pattern of the disease Gefter *et al* (1947) and Donhardt (1953) considered the intensity of organic myocardial involvement to be the determining factor, however electrocardiograms were not obtained in any of the eleven fatal cases in the series of Gefter *et al* (1947), and the marked differences in the

occurrence of electrocardiographic abnormalities in the series of Donhardt (1953) in non-paralytic and paralytic cases (25 per cent. and 35 per cent., respectively) and in patients with respiratory paralysis (88 per cent.), rather militate against their organic myocardial origin. Weinstein and Shelokov (1951) stated the frequency of abnormal tracings to be related to the severity of paralysis but not to the type of involvement. Manning and Yu (1951) on the other hand, found more abnormal records in patients with bulbar or high cervical paralysis, and in their series no correlation could be established with the severity of paralysis. Georg *et al.* (1953) concluded that the abnormalities were most closely correlated with the degree of respiratory insufficiency.

The present series may account for some of the discrepancies. Two groups of electrocardiographic abnormalities were recognized: (1) Very few, widely different, changes (totalling 12 per cent.) carried a mortality of 80 per cent. and probably indicated an organic (poliomyelitic) involvement of the myocardium. These changes were unrelated to the type of disease and showed a uniform distribution in all sub-groups. This is in accord with the observations of Spain *et al.* (1950) that the incidence and severity of the histological myocardial changes cannot be correlated with the clinical type of the illness. Also the existence of a viraemic phase in the initial stages of poliomyelitis (Horstmann *et al.*, 1954) tends to favour an equal involvement of the myocardium. (2) The majority of the abnormalities noted (141 or 88 per cent.) were of no prognostic significance, but occurred more frequently in the sub-groups with the highest death rates and showed some correlation with the degree of respiratory embarrassment; these changes were uniform and non-specific.

In this series of 345 life-threatening cases, 144 terminating fatally, the incidence of abnormal tracings was 50 per cent., and no higher than the incidence of 54 per cent. (only definitely abnormal tracings considered) in the series of Manning and Yu (1951) with only eight fatal cases in a total of 150. This can hardly be fully accounted for by differences in the criteria of interpretation. Moreover, even in non-paralytic cases electrocardiographic abnormalities occur frequently. Donhardt (1953) reported changes in 25 per cent. of such cases.

Considering that most changes in this series (as in the series of Bradford and Anderson (1950), Fox *et al.* (1953), and Georg *et al.* (1953)) were of the type found in many systemic diseases, and that

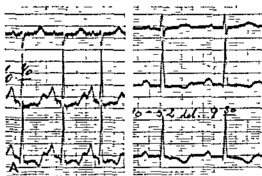


Fig 51A

Right heart strain pattern with marked tachycardia (heart rate 185/min) Record obtained in a 33-year-old woman with a right-sided atelectasis who died on the third day after admission

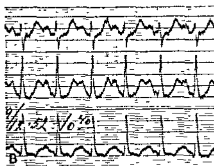


Fig 51B

[illegible]

a stay of two months Second record obtained while atelectasis was disappearing No third record is available in this case

only relatively few abnormalities might be indicative of pulmonary disease, it appears that the majority of electrocardiographic changes in poliomyelitis show a basic occurrence determined by the systemic character, *i.e.* the constitutional effects, of the disease and are less influenced by other factors, such as the degree of respiratory insufficiency and circulatory disturbance.

The electrocardiographic changes occurred early in the disease and tended to revert to normal within a few weeks. Of the twenty patients whose electrocardiograms showed serious changes fifteen died within ten days from the onset of the meningeal stage of the disease. One survived for twenty-seven days.

The clinical diagnosis of myocarditis could not be made with certainty during the epidemic. Such criteria as increased tachycardia, fever, cyanosis, dyspnoea, sudden deterioration of the condition, and even congestive heart failure usually indicated the development of pulmonary atelectasis In retrospect, however, arrhythmias, P-wave changes and conduction disturbances appear suggestive of a myocarditis, and should call for prudence with regard to prognosis Blood-pressure readings proved of no value in doubtful cases

The right heart strain pattern has received special attention in this study It has previously been described by Bradford and Anderson (1950) in two patients with bulbospinal polio of severe grade who appeared to have marked pulmonary oedema The pattern is not mentioned by Gefter *et al.* (1947) but typical changes are manifest in one of the tracings published. So far no satisfactory explanation has been given of its implications in poliomyelitis.

Contrary to most other electrocardiographic changes the right heart strain pattern in our patients could always be correlated with an obstructive atelectasis. Where the atelectatic lobe re-expanded the electrocardiographic changes reverted towards normal (Figs. 51 A and B) In long-standing atelectases the characteristic pattern tended to fade away (Fig. 52). The development of a right heart strain pattern and basic atelectasis was associated with an increased tachycardia and a rise in systemic blood pressure

Artificial respiration has been used in all patients showing a right heart strain pattern, but appeared to have no direct bearing on the electrocardiographic changes. The form of positive-pressure ventilation used (bag ventilation) discourages atelectasis and helps to expand atelectatic lungs Aspiration of pooling secretions moreover, is facilitated by combination of tracheotomy and bag ventilation.

Incorrectly administered bag ventilation may favour emphysema, and the preponderance in this series of electrical axes shifted to the right may be indicative of adverse effects of incorrect bag ventilation. (*Cf.* chapter on respiratory (p. 53) and circulatory (p 54) effects of artificial respiration)

Displacement of the heart by atelectasis failed to explain the electrocardiographic changes, and probably the right heart strain

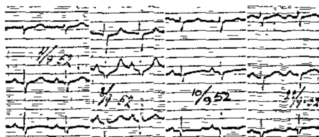


Fig 52

Sequence of electrocardiographic changes in a five-year-old boy with persisting atelectasis Second tracing coincident with the development of atelectasis Note deep Q_3 wave that has disappeared two days later Also note marked T wave changes The fourth tracing obtained two weeks after development of atelectasis is similar to the first tracing

pattern suggests altered pulmonary haemodynamics following development of atelectasis, namely a rise in pulmonary arterial and right ventricular pressures The Q_3T_3 pattern may be suggestive of similar processes

The distinctive features of the pulmonary circulation and some experimental evidence seem to favour such a hypothesis The pulmonary circulation is a low pressure system carrying the same amount of blood as the systemic circulation, the blood passes only a single organ, and is in intimate contact with the surrounding atmosphere through the capillary system of the alveolar walls The blood distribution within the lungs is mainly regulated by local mechanical conditions

In animal experiments reported by von Euler and Liljestrand (1946) hypoxia, induced by breathing 10–11 per cent of oxygen, and, to a slighter degree excess of carbon dioxide, caused a pulmonary hypertension The pressure rise was due to a direct action of the low oxygen tension on the pulmonary vessels; vagotomy and extirpation

of the stellate ganglia did not influence the degree of hypertension This local regulation of blood flow will permit of an adequate distribution of blood through the various parts of the lungs according to the efficiency of aeration.

The absence of vasomotor reflexes was confirmed by Daley *et al* (1951), who showed that the pulmonary hypertension produced by injection of lycopodium spores in the pulmonary arterial system of dogs, was caused by mechanical occlusion of pulmonary arterioles and was not due to a generalized pulmonary vasoconstriction

In normal human subjects short periods of hypoxia, induced by breathing a ten per cent oxygen mixture, caused a considerable pulmonary hypertension and a pressure rise in the right ventricle (Motley *et al.*, 1947). The increase in pressure was maximal within two to four minutes and was associated with a decrease in cardiac output and a slight rise in heart rate and systemic blood pressure The calculated pulmonary vascular resistance was almost doubled during hypoxia

During the first days and weeks of experimental pulmonary atelectasis in dogs, Bjork and Salén (1950) observed a considerable decrease in the blood flow through the atelectatic parts (to about 50 per cent. of the normal) Addition of venous blood from non-ventilated areas caused a corresponding reduction in the oxygen content of the arterial blood. In acute total atelectasis the decrease in blood flow was of the same order as that due to the increased resistance in the capillary bed of a lung breathing 100 per cent N_2. In persisting atelectasis the blood flow diminished with the age of the atelectasis, and the arterial oxygen deficit disappeared Similar conditions obviously apply to man, *e.g.* in cases of bronchial carcinoma.

From the above observations it would appear that acute hypoxia, whether due to low oxygen breathing or caused by acute atelectasis, gives rise to a pulmonary hypertension. The hypertension is elicited locally either by a pulmonary arteriolar constriction or by changes in the alveolar capillaries. The right heart strain pattern in poliomyelitic patients appears representative of a pulmonary hypertension caused by the hypoxia in acute atelectasis. In persisting atelectasis the hypoxia gradually disappears, and the electrocardiographic changes concomitantly revert towards normal

CHAPTER XVII

RENAL CALCULI AND ARTIFICIAL VENTILATION

By P Astrup and T Sottrup

It is a well-known fact that renal calculi, composed of calcium phosphate, may appear in patients bedridden for long periods of time. This might be expected in paralyzed patients too, and more frequently than in non-paralyzed patients, because the loss of calcium and phosphate is marked, and urinary infections are frequent

In fact, however, the incidence of renal calculi in patients with poliomyelitis, and especially among those with respiratory paralysis was so striking that we were led to think that artificial ventilation might in some way enhance the formation of renal calculi

FREQUENCY OF CALCULI

Up to January 1, 1956, renal calculi were demonstrated in twenty patients either by X-ray or by the passage of calculi in the urine Furthermore, five additional patients had otherwise unexplainable haematuria at one time or another The twenty patients with unquestionable calculi correspond to twenty-five per cent of all surviving patients with severe paralysis No less than seventeen of those had quadriplegia while three had severe paraplegia of the upper extremities. With one exception they were all submitted to artificial respiration from under one month to more than three years The diagnosis of calculus was established from four to twenty-four months after the acute stage All of the patients had urinary infection for shorter—or mostly longer—periods of time prior to the appearance of the renal calculi. As was to be expected, urinary infection was initiated during the period of paralysis of the urinary bladder so often present in the acute stage

All the calculi passed with the urine were analysed and found to be composed of calcium phosphate

INVESTIGATIONS

The following investigations concerning a possible relationship between the formation of renal calculi and artificial respiration were undertaken.

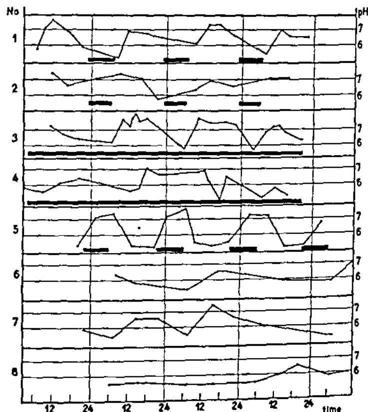


FIG 53

Variations of urinary *p*H values in five patients (Nos 1, 2, 3, 4, and 5), treated in respirators during the period of time indicated by the black areas—in *two normal controls* (Nos. 6 and 7), and in *one patient* with chronic respiratory acidosis (No 8)

Over a prolonged period every specimen of urine passed by a selected number of patients was examined in respect of. *p*H, sodium, potassium, calcium, phosphate, chloride, ammonium, and titratable acid An attempt was then made to correlate the results with the

type of ventilation (artificial or spontaneous), the ventilatory volume per minute, and the pH and pCO_2 in the arterial blood.

Variations of the pH in the urine

In patients who had artificial respiration for only a part of the twenty-four hours the variations of the urinary pH were very constant (Figs. 53 and 54). Patients No 1, 2, and 5 had artificial ventilation only during the night as shown by the black areas

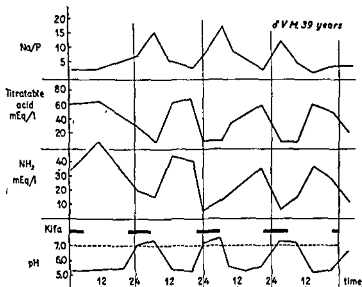


FIG 54

Variations of urinary pH values, content of ammonium, titratable acid, and the ratio between excreted amounts of sodium and phosphorus in a patient treated in a respirator during the night

Fig 53 shows that in patients Nos 1 and 2 the urine regularly became alkaline during the *daytime* with a maximum pH around noon This could be constantly reproduced during the whole experimental period. In patient No 5 similar regular variations were found, but in this case the urine was alkaline during the *night*.

In an attempt to correlate these variations of urinary pH with the possible presence of respiratory alkalosis the pH and the pCO_2 of

the blood were determined at various points The blood pH showed minimal variations—less than 0 05 *pH units—in the individual* patient, although it was invariably highest in the morning when artificial respiration stopped. The pCO_2 values, also showed minor variations. The minute volume of ventilation was practically the same in the two patients with the highest pH during the daytime, irrespective of their being in the respirator or not.

In patient No. 5, on the other hand, who excreted an alkaline urine during the night, the ventilation per minute was constantly lower in the respirator than outside it—five to six litres per minute in the respirator, seven to nine litres per minute while breathing spontaneously

In two patients having permanent artificial respiration (Fig 53, Nos. 3 and 4) the variations of the urinary pH were found to be the same as in patients Nos. 1 and 2, *i.e.*, alkaline urine was passed during the daytime. The same tendency was found in two normal controls, but was less pronounced (Fig. 53, Nos. 6 and 7).

In one patient (Fig. 53, No. 8) with relative respiratory insufficiency —breathing spontaneously although with difficulty—throughout the twenty-four hours the urine was always acid without much variation. This patient was constantly under-ventilated, his blood pH being about 7 30, and the pCO_2 ranging between 50 and 60 mm. Hg.

Excretion of NH_4^+, Na^+, K^+, Cl^- and titratable acid

In specimens of urine with a high pH the content of NH_4^+ and titratable acid was invariably low in all the patients examined (Fig 54). The upper curve shows that the ratio Na/P increases with increasing pH, indicating that greater amounts of secondary phosphate are excreted instead of primary phosphate. The excretion of Na^+, K^+ and Cl^- varied very little in consecutive specimens of urine.

Excretion of Ca and P

The excretion of Ca in the urine of poliomyelitis patients was moderately increased, amounting to 150 to 350 mg. per twenty-four hours. All the patients examined had been ill for more than four months. The great Ca loss early in the disease thus preceded the experimental period.

The combined ionic concentrations of Ca^{++} and HPO_4^{--} were calculated (mol /litre) in a series of urines. In many specimens with

a high pH the solubility product was exceeded, and numerous crystals of secondary calcium phosphate were demonstrated microscopically.

DISCUSSION

The rhythmic pH variations in the urine are basically the same in ormal individuals as in poliomyelitis patients, although a little more ronounced in the latter. These variations can, without difficulty, be explained as post-prandial pH variations in the urine. The secretion of hydrochloric acid in the stomach of these patients with respiratory deficiency is presumably not compensated through the normal interplay of the pulmonary and renal regulatory mechanisms, but is mainly dependent on the renal regulation alone. This at least is the case in patients who constantly have artificial respiration with a fixed ventilatory volume per minute. In the patients with low vital capacities and laborious spontaneous breathing the kidneys presumably take over a greater part of the acid-base regulation than normally.

We do not know if this explanation is correct, but it covers admirably the results of our investigations. A continuous registration of the pH, and the pCO_2 values, and the alkali reserve (bicarbonate at 40 mm Hg) would have been desirable, but was impossible in the circumstances.

Without any doubt the increased excretion of calcium in the urine so often found in patients with severe paralysis, in conjunction with high urinary pH, values enhances the risk of deposition of secondary calcium phosphate in the urinary pathways. Presumably this state of affairs explains the high incidence of renal calculi found in patients having artificial respiration. Infection is a contributory cause.

During the first few weeks of the disease characterized by pronounced decomposition of muscular proteins, numerous examinations constantly revealed low pH values in the urine, presumably due to increased excretion of sulphate and phosphate ions, counteracting the sedimentation of calcium phosphate in this phase, where the calcium loss is considerable. The period of rhythmic pH variations occurs at a later stage.

The most important precaution against the formation of renal calculi is to avoid infection of the urinary tract—more easily said than done. The second is to maintain an acid urine. This is equally difficult but achievable if it is possible to reduce ventilation durin

the daytime. We tried continuous administration of ammonium chloride in suitable doses but it often had to be abandoned because of dyspeptic symptoms. *Possibly calcium could be eliminated in soluble* form during the post-acute stage by administration of ethylene-diamine-tetra-acetate.

CHAPTER XVIII

RESULTS

By F Neukirch and T Sottrup

In this chapter the results of the treatment of 318 patients with life-threatening poliomyelitis admitted after the introduction of the therapeutic methods previously described, i e., from August 26, 1952, to March 2, 1953, are summarized The date of reference is January 1, 1956.

TABLE XXVIII

318 Patients Admitted from August 26, 1952, to March 2, 1953
Date of Reference January 1, 1956

	Adult Males	Adult Females	1–14 years	less than 1 year	Total
No of patients	81	72	159	6	318
No of deaths	42	23	51	2	118
Mortality rate	52%	32%	32%	(33%)	37%
Still artificial respiration	9	8	7	1	25
Spontaneous respiration, still cannula	—	—	1	—	1
Discharged	30	41	100	3	174

Table XXVIII gives a survey of all the life-threatening cases treated during this period. Approximately half of these patients were adult —a marked preponderance compared with the general distribution of all patients, paralytic and non-paralytic This was in conformity with previous experience Out of 318 patients 264 were submitted to tracheotomy and of these 232 were treated with positive pressure ventilation

The case fatality rate for the whole series is 37 per cent , with males showing an excessive mortality (males 52 per cent , females 32 per cent) We cannot offer any explanation for this difference

Of 118 patients who succumbed 20 died within twenty-four hours of admission, and no less than 74 patients were dead within seven

days, indicating the extraordinary severity of the epidemic and the rapid progression of the disease during the acute phase.

The condition of the surviving patients at January 1, 1956, is as follows:

Some form of artificial respiration is still required in 25 cases Some of these cases need respiratory aid only for a few hours daily, but the majority (75 per cent.) require it for the greater part of the twenty-four hours and must be considered chronic, life-long respirator patients Of these twenty-five patients five are rid of their tracheal cannula, while this is still needed in twenty cases, because they cannot clear the air passages sufficiently of secretions and have to be assisted by frequent intratracheal aspirations

175 patients are now totally independent of artificial ventilation, though some of them still have a more or less reduced vital capacity. Of these, 174 have left the hospital, but a few have required re-admission because of intercurrent respiratory infection Some have had evident atelectasis necessitating renewed artificial ventilation, postural drainage, and lung-physiotherapy. Two of those readmitted were in a very precarious state.

A comparison of results at January 1, 1956, with those at April 1, 1953, shows that in April 1953 no less than thirty-nine patients were totally or partially dependent on artificial ventilation. During the intervening thirty-three months two have died—both after having left the hospital—and a further twelve have become independent of artificial respiration

Concerning the 200 surviving patients with life-threatening poliomyelitis (318 − 118) 75–80 are completely without paralysis or have only insignificant sequelae, while another 75–80 have slight or moderate paralysis of the extremities, enabling them to pursue their ordinary work or to take up special jobs after re-education Finally 40–50 patients still have severe sequelae, most of them with quadriplegia of varying degree, and presumably none of these will ever become rehabilitated. They must be considered as "chronics" requiring constant help in most respects. Among them, of course, are all the patients still dependent on artificial respiration.

Fig. 55 shows a graph of the 318 patients with life-threatening poliomyelitis divided into the six groups previously mentioned. The different areas on the histogram refer to the numbers of patients discharged, to those on spontaneous respiration or artificial respiration, and to those dead.

Of the twenty-five chronic respirator patients now left no less than twenty-one are to be found in *group C—pure spinal* respiratory

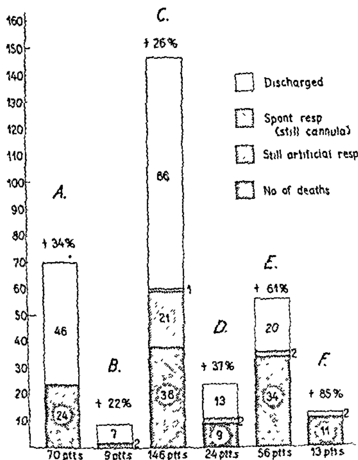


FIG 55

Results of treatment in *318 patients with life-threatening poliomyelitis, according* to classification adopted Date of reference January 1, 1956

insufficiency—and four in groups D and E—paralysis of respiratory muscles with pharyngeal paralysis or cerebralia.

In Table XXIX the 318 patients with life-threatening poliomyelitis *treated* after the introduction of bag ventilation—*i e*, manual *positive* pressure ventilation—are tabulated in consecutive groups of fifty patients. The only patients omitted are *the four patients* mentioned earlier who were dead on admission.

TABLE XXIX

MORTALITY RATES—NEW METHODS OF TREATMENT INTRODUCED AUGUST 26, 1952. DATE OF REFERENCE: JANUARY 1, 1956

Group	Period of admission	No of cases	Died	Per cent.
I.	July 7–August 25	30	26	87
II.	August 26–September 7	50	25	50
III	September 7–September 23	50	23	46
IV.	September 23–October 5	50	22	44
V	October 6–October 20	50	15	30
VI	October 21–November 6	50	18	36
VII.	November 7–December 19	50	13	26
VIII	December 20–March 2	18	2	11
Total II—VIII		318	118	37

Group I comprises thirty patients with life-threatening poliomyelitis treated before August 26, *i e*, before the introduction of manual bag ventilation. The mortality was—as in former years—80–90 per cent.

The following groups show a gradual fall in mortality rates from 50 per cent in group II to 26 per cent. and 11 per cent respectively in groups VII and VIII The decreasing mortality is due to the fact that gradually we were able to cope more and more effectively with the dangerous complications It is our firm impression that the character of the life-threatening cases was uniformly severe throughout the whole epidemic period.

Judging from the results obtained in the Copenhagen epidemic in 1952 it is presumably safe to say that with our present knowledge an over-all mortality of about 25 per cent (in the life-threatening cases) might be expected in future epidemics of comparable severity. Considering the enormous destruction in the brain stem found histologically in those who died, a certain number of deaths must be reckoned with even in spite of optimal equipment and expert knowledge

CHAPTER XIX

AUTOPSY FINDINGS

BY B VIMTRUP, ERNA CHRISTENSEN AND K SCHOURUP

THE material to be analysed comprises 115 cases of poliomyelitis. The approximate duration of illness at death is shown in Table XXX.

TABLE XXX

Duration of illness	No of patients		Percentage of entire material
0–2 days	28	59	51
3–4 days	31		
5–6 days	15	33	29
7–10 days	18		
11–15 days	8	23	20
16–20 days	6		
Over 20 days	9		

By employment of a special technique, the entire central nervous system with the spinal ganglia was removed *in toto*, so that injury to any section of the spinal cord was avoided.

Structural Changes

In all acute cases in which death occurred within two weeks after the onset of the illness the spinal cord was swollen and remarkably soft The spinal leptomeninges were hyperaemic and in a few cases opaque or oedematous

On section the anterior horns showed more or less pronounced hyperaemia most commonly met with in the lumbar swelling and at the cervical and upper thoracic levels In several cases some segments exhibited haemorrhage in the grey substance The medulla oblongata was also hyperaemic and soft while the cerebrum and the rostral part of the brain stem were normal in consistency. There was only a slight increase in the amount of cerebrospinal fluid The dura was normal.

Histology

A survey of the localization and severity of histologically verified pathological processes is given in Table XXXI.

TABLE XXXI

LOCALIZATION AND SEVERITY OF INFLAMMATORY AND DEGENERATIVE PROCESSES

No. of cases examined	Localization	No of cases with inflammatory and degenerative processes	Particularly severe lesions
105	Cerebral cortex	31	8
106	Hypothalamus	79	16
100	Mesencephalon	75	35
115	Pons, medulla oblongata	114	114
115	Spinal cord	115	115
42	Spinal ganglia	14	—

In addition anoxic changes without any inflammatory infiltration were found in the cerebral cortex in seven cases.

The *motor cortex* often showed mild patchy involvement with local hyperaemia and perivascular infiltration with leucocytes, lymphocytes and large mononuclear cells, furthermore, the number of microglia cells was increased. In some cases, small foci with very numerous polynuclear leucocytes were seen. The ganglion cells—especially the pyramidal cells—in the areas involved were swollen, chromatolytic or chromophobic, with karyolysis; proliferation and vacuolization of the microglia was also seen. In the *hypothalamus* the lesions were of the same nature, but here the perivascular infiltration was often predominant The supra-optic nucleus was affected most frequently. In some cases the paraventricular nucleus and the more caudal areas were also involved

In the *mesencephalon* the inflammatory processes were most conspicuous in the caudal part of the oculomotor nucleus and in the substantia nigra. Less frequently the trochlear nucleus was affected.

In the *pons* and *medulla oblongata* too, the affection had certain sites of choice. In the striae and the nuclei pontis slight perivascular

infiltration was seen, but only in very few cases. In the medulla oblongata the ventral part and the olive merely showed hyperaemia and occasionally infiltration with mononuclear cells in the vascular sheaths. The dorsal part in particular showed affection of the nuclei of the cranial motor nerves and of the formatio reticularis in which total necrosis was observed in some cases, while in others a difference could be made out between the medial part with the large ganglion cells and the lateral part with the small ganglion cells In all our cases but one, bulbar poliomyelitis had been diagnosed clinically, and the formatio reticularis as well as the medial dorsal motor nucleus of the vagus were involved in all these cases Deiter's nucleus was attacked only in a few cases and the same applied to the motor nucleus of the trigeminus, whereas the nucleus ambiguus and the nucleus facialis were involved in several cases, and in a few the *abducens nucleus.*

In the *spinal cord* the extent and severity of the disease varied greatly in different cases As a rule the lesions were predominantly located to the anterior horn at certain levels while others were almost normal. However, patchy involvement of the posterior horn was encountered

The minimal change in the spinal cord attracting attention was hyperaemia in the anterior grey commissure and in the central part of the anterior horn Sections stained with Gallocyanin usually showed a rather intense staining of the Nissl-substance in the ganglion cells in these areas Presumably this chromophilia was the first morphological evidence of an affection of the ganglion cells Slightly more affected areas in the anterior horns showed more pronounced hyperaemic infiltration of the vessel walls with mononuclear and polynuclear cells and diapedesis of erythrocytes In such areas degeneration and disintegration of ganglion cells, proliferation and vacuolization of microglia cells and some diffusely infiltrating leucocytes were often seen. The large ganglion cells may show very pronounced regressive and degenerative changes, *i e* chromophobia, vacuolization of the cytoplasm, karyolysis and ragged outlines of the cell body, which was often surrounded by numerous leucocytes Some ganglion cells were invaded by leucocytes that caused proteolysis of their cytoplasm. In some cases almost all of the large motor ganglion cells were severely damaged or totally dissolved In other cases only certain groups of cells were attacked while others appeared almost normal.

In many cases, especially when the illness had lasted for more than four to five days, all the above-mentioned changes were encountered and often numerous microglia cells had become markedly vacuolized. Several ganglion cells had disappeared completely, and in their place groups of degenerating leucocytes and microglia cells were found. Furthermore, plasma cells appeared in the oedematous nerve tissue. Certain cases displayed areas of necrotic nervous tissue with haemorrhage and almost complete destruction of both glial cells and ganglion cells.

It should be noticed that one anterior horn may be severely attacked while the contralateral anterior horn of the same segment appears normal. This fact presumably lends support to the view that hyperaemia and other vascular changes are secondary to virus damage to the nerve cells.

While in specimens from the acute phase the spinal cord was found to be swollen and highly vulnerable, in cases that had persisted for several weeks it was reduced in volume, especially the anteroposterior diameter. This feature was most pronounced in sections from the cervical and lumbar enlargements

It has been emphasized that the lesions as a rule were most severe in the central part of the anterior horn, though often the entire anterior horn was involved with sometimes parts of the corresponding posterior horn.

Thus in thirty-eight cases we found the entire anterior horn and part of the posterior horn severely damaged or almost necrotic In seventy-seven cases a selective destruction of ganglion cells was observed in the central part of the anterior horn, while columns of the big motor cells in the ventral part were fairly well preserved; the anteromedial group of cells in twelve cases, the anterolateral group in thirty-seven and the anteromedial group as well as the anterolateral group in twenty-eight cases. It must be pointed out, however, that by no means all of these preserved ganglion cells showed normal structure. They often displayed chromophilia or chromolysis but only minor changes of their nuclei.

When we try to correlate our observations with the duration of illness and the severity of clinical symptoms, we reach the conclusion that the lesions described are stages in a process that gradually leads on to more or less total destruction and disappearance of large

tory processes are regressing—also proliferation of astroglia and oligodendroglia, so that the process turns into sclerosis

Thus chromophilia was particularly pronounced in the early acute stage Neuronophagia was seen regularly in the first three days Advanced chromatolysis and pale, irregular shadows of total disintegration of ganglion cells was observed in all the more protracted cases

As an illustration of the relation of the clinical symptoms to the histological changes, brief abstracts of nine case-histories and the relevant histological findings will be given In some of these cases the illness was of short duration, in others more protracted

Case Histories

Case 1 (Rec No 49,699)

Woman, aged nineteen, who died three days after the onset of illness, two days after admission

On admission the spinal fluid showed pleocytosis, but no paralysis was found During the following twenty-four hours paralysis of swallowing developed, together with paralysis of the flexor muscles of the left arm Tracheotomy was performed and positive pressure ventilation instituted, but pulmonary oedema, fall in blood pressure, haemoconcentration, and increasing hyperthermia developed

In spite of manual positive pressure ventilation, 50 per cent glucose and concentrated dry serum intravenously, she died two days after admission

Pathology

Sections from the *cerebrum* showed encephalitis in the hypothalamic region, especially in the paraventricular nucleus and surroundings

In the *mesencephalon*, round the Sylvian aqueduct and especially in the oculomotor nuclei, hyperaemia was seen, together with perivascular haemorrhage, swelling and chromophobia of the ganglion cells, besides a solitary focus with necrosis and accumulation of macrophages and lymphocytes

The *pons* and *medulla oblongata* showed extensive inflammatory foci with necrosis localized to many of the nuclei of cranial nerves, especially the dorsal motor nucleus of the vagus, the formatio reticularis, and the hypoglossal nucleus

In sections from the cervical and lumbar enlargements and the thoracic part of the spinal cord the changes were less pronounced While the centrally situated ganglion cells in the anterior horn were destroyed, the anteromedial and the anterolateral ganglion cells were preserved Accumulation of microglia cells was seen, and perivascular infiltration with lymphocytes and leucocytes, here and there confluent. Often the infiltration

was asymmetrical, one anterior horn being *more affected than the* other, and the inflammatory infiltration changed from one segment to another.

Interpretation

The marked hyperthermia might be ascribed in part to the affection of the hypothalamus. Presumably the paralytic cough and the falling blood pressure were correlated with the lesions in the formatio reticularis and nucleus ambiguus. The partly preserved anterior horn cells in the spinal cord afforded an explanation why paralysis of limb muscles was merely slight. The histological changes appeared *to be more pronounced than the clinical symptoms of paralysis, but* during the last twenty-four hours the patient was so debilitated that the presence of oculomotor paralysis and progressive limb paralysis could hardly have been ascertained.

Case 2 (Rec. No. 50,244)

Girl, four years old, who died three days after the onset of illness, two days after admission

On admission the patient had a high fever and headache She was unable to move her head or sit up, but there was no limb paralysis or swallowing difficulty. The two last-mentioned symptoms developed during the first twenty-four hours in hospital, and paralytic cough also appeared *In spite of manual positive pressure ventilation, the patient* died with cyanosis and pronounced pulmonary oedema

Pathology

The *motor cortex* showed hyperaemia, oedema and swollen chromophobic ganglion cells with large pale nuclei, but no inflammatory phenomena

Sections from the *hypothalamic nuclei* showed hyperaemia with perivascular and diffuse leucocyte and lymphocyte infiltration, besides ganglion cell degeneration, *viz* swelling, chromatolysis, chromophobia, or complete disintegration.

In the *pons* and *medulla oblongata* the inflammatory changes were even more pronounced in nearly all the nuclei of the cranial nerves, with the exception of the acoustic and vestibular nuclei. In large areas the tissue was completely necrotic with diffuse leucocytic and lymphocytic infiltration The vessels were dilated and hyperaemic with perivascular haemorrhage Apart from very *slight hyperaemia, the ventral part of the pons* and medulla oblongata was normal.

The *spinal cord* was also extensively affected throughout the entire [illegible] Here and there, however,

the site of intensive inflammation and necrosis In sections from the lumbar enlargement stained with Weil's stain, the medullary sheaths were seen to be preserved although somewhat swollen, and there was merely a suggestion of fat precipitation in Sudan-stained sections, presumably indicating how slight is the affinity of the polio virus for the white substance

Interpretation

The hyperthermia and cyanosis might be explained as of hypothalamic origin, while the deglutitory difficulty and the paralytic cough undoubtedly were attributable to the affection of the respective nuclei in the medulla oblongata The presence of some motor ganglion cells in the spinal cord explained why paralysis of the extremities was not total

Case 3 (Rec No 50,184)

Man, aged thirty-two, who died four days after the onset of illness, two days after admission

On admission, the patient presented paralytic cough, lowered function of the soft palate, paralysis of both upper extremities, difficulty in moving its head, impaired function of the abdominal muscles together with npairment of thoracic respiration, high temperature and high blood essure

Immediately after admission, tracheotomy was performed and positive essure ventilation instituted, but after nine hours the patient showed gressive deterioration with subsequent development of pulmonary ema, shock and hyperthermia

Pathology

The *motor cortex* showed moderate inflammatory reaction, here and there with slight perivascular accumulation of lymphocytes, leucocytes and microglia cells, and marked hyperaemia and oedema, in addition to anoxic changes The ganglion cells were nearly all completely chromatolytic, swollen or slightly shrunk, with pyknotic nuclei

In the *hypothalamus* there was diffuse hyperaemia and oedema together with some scattered inflammatory foci with disintegration of ganglion cells, both in the medial and lateral nuclei The *mesencephalon* too showed diffuse hyperaemia, capillary dilatation and perivascular haemorrhages, besides pronounced focal inflammation with incipient necrosis and accumulation of leucocytes, lymphocytes and macrophages in the region of the oculomotor nucleus

In the *pons* and *medulla oblongata* the findings were normal ventrally In the dorsal part, focal lesions were seen in the right facial nucleus, the entire formatio reticularis including the medial dorsal motor nucleus of the vagus, and in the hypoglossal nucleus These lesions were characterized by oedema, hyperaemia, perivascular haemorrhage and infiltration with

lymphocytes, besides complete or partial disintegration of the ganglion cells. The other parts of the medulla oblongata showed merely moderate inflammatory changes with some degree of ganglion cell degeneration—in particular, swelling and chromatolysis of the tigroid substance.

In the spinal cord the affection was most pronounced in the cervical enlargement which showed total necrosis of both anterior horns, partial necrosis of the lateral horn, and in a lesser degree, of the posterior horn, in addition to considerable hyperaemia and perivascular infiltration with leucocytes.

In the *thoracic cord* the inflammation was segmental, showing all gradations of change—normal, hyperaemic, and inflamed areas as well as total or partial disintegration of anterior motor cells. The intensity of the inflammatory reaction decreased caudally, so that the *lumbar cord* showed merely slight inflammatory infiltration in one anterior horn together with damage to the anterior motor cells in a single segment. The contralateral anterior horn and the other segments showed merely moderate hyperaemia with swelling and chromophobia of the anterior horn cells.

Interpretation

Presumably the hyperthermia and ventricular atony were of hypothalamic origin. The development of cyanosis, paralytic cough, paralysis of the soft palate and the state of shock might be attributable to the severe changes in the formatio reticularis and to the partial disintegration of the ambiguus, hypoglossal and vagal nuclei. The pathological changes in the central nervous system, especially the injury to the vagus, might have played a rôle in the appearance of pulmonary oedema. The extensive paralysis of both upper extremities was explained by the areas of necrosis seen in both anterior horns of the cervical swelling of the spinal cord. The impaired, but not totally abolished thoracic breathing corresponded to the partial preservation of the anterior horn cells in the thoracic cord.

Case 4 (Rec. No. 49,700)

Boy, five years old, who died four days after the onset of illness. Prior to admission, he was febrile and poorly, with increasing difficulty in swallowing.

On admission, there was pharyngeal paralysis with large amounts of [illegible] or limb

In spite of the treatment he died six hours after admission

Sections from the motor region of the *cerebral cortex* showed no inflammatory infiltration, merely slight swelling and chromophobia of ganglion cells

In the *hypothalamus* only the posterior part showed slight perivascular infiltration with lymphocytes in the vicinity of the 3rd ventricle, but the ganglion cells were more chromophobic and swollen here than in the cortex

In the *mesencephalon* some inflammatory foci were seen in the oculomotor nuclei with lymphocytes, leucocytes and plasma cells, chiefly perivascular, to a lesser degree in the brain tissue proper Many ganglion cells were swollen and chromatolytic or pyknotic

In the *pons* and *medulla oblongata* the dorsal half showed increasing perivascular inflammatory infiltration, hyperaemia and affection of the nervous tissue In many areas of the medulla oblongata these changes were confluent and more pronounced, corresponding to the abducens, facial and hypoglossal nuclei They were also observed in the medial dorsal motor nucleus of the vagus and in the formatio reticularis

In the *spinal cord* the inflammation was most pronounced in the cervical section, where the entire grey substance was damaged, the anterior horns showing the most severe changes, so that few anterolateral ganglion cells were preserved. The intensity of inflammation decreased caudally through the thoracic and lumbar sections, where only the anterior horns were affected and to a lesser extent than in the cervical cord

Interpretation

The histological findings appeared considerably more severe than the clinical symptoms noted, but in this case the disease took such a fulminant course as to make it impractical in the last hours ante mortem to register all clinical symptoms

It is a peculiar fact that this patient had no respiratory paralysis at the time of admission since the changes in the entire formatio reticularis were so pronounced Probably, however, the inflammatory process had first attacked the medial nucleus (nucleus megacellularis), which is of particular importance to the circulation Presumably the deglutitory difficulty and the paralysis of the soft palate were due to destruction of the ganglion cells in the nuclei of the IX–XII cranial nerves On admission no limb paralysis was noted in spite of considerable injury to ganglion cells especially in the cervical cord

Case 5 (Rec No 50,158)

Woman, aged twenty-nine, who died ten days after the onset of illness, eight days after admission

When first seen she was frightened, *unable to swallow*, her speech was slurred, and there was accumulation of secretions in the nose and throat, bilateral pharyngeal paralysis and slight unilateral (left) facial paralysis. Respiratory movements were noted both of the chest and abdomen in spite of manifest dyspnoea. *No limb paralysis was recorded. The temperature* was high, the blood pressure raised, and the spinal fluid showed pleocytosis. At first she was placed in a cuirass respirator, but some hours after admission tracheotomy was performed and she was given positive pressure ventilation. She *remained restless and hazy and during the last seven days* she was unconscious, though still responding when roused. There was continuous high fever and appearance of atony of the stomach, falling blood pressure and increasing infiltration in the lungs. During the last *four days she developed uraemia with convulsions. No paralysis of the* limbs was recorded. The pupillary reflexes were preserved, but spontaneous eye reflexes were absent.

Pathology

Macroscopic examination of the brain revealed approximately in the *middle of the medulla oblongata—corresponding to the formatio reticularis*—a localized area infiltrated with blood where tissue appeared to be undergoing early necrosis.

Microscopic examination of sections from the motor region of the cortex showed exclusively anoxic changes in the ganglion cells with pyknosis of the nuclei and chromatolysis, besides shrinkage of the protoplasm, in a few places there were nodules of glia cells, but no inflammatory reaction was seen.

[illegible] seen in the *hypo-* [illegible] re [illegible] o- [illegible]

In the *pons* and *medulla oblongata* the most pronounc[illegible] re found in areas corresponding to the facial and abducens nuclei, the dorsal motor nucleus of the vagus, the formatio reticularis and the hypoglossal nuclei, that is, in the area in which the focus was observed macroscopically. Microscopically this focus was characterized by areas of necrosis, dilatation of vessels, hyperaemia, perivascular haemorrhages and perivascular infiltration with lymphocytes and macrophages, destruction of the ganglion cells, oedema and necrosis.

Sections from the spinal cord showed extensive inflammatory processes in the cervical cord with necrosis in the anterior horns. In the thoracic and lumbar sections of the cord some preserved anterior horn cells were seen anterolaterally and anteromedially, even though a good many of them were the site of varying degrees of degeneration, and there was moderate infiltration with lymphocytes and microglia cells. The inflammatory reaction was distinctly segmental and most pronounced centrally in the anterior horns.

Interpretation

In this patient the degenerative and inflammatory lesions were unusually marked in the medulla oblongata and in the entire brain stem, but decreased down through the spinal cord; and in the motor cortex only simple anoxic changes were seen.

On admission, hyperthermia and high blood pressure were noted, besides restlessness and haziness which developed into unconsciousness during the last seven days, all in keeping with the changes found in the hypothalamus Presumably also the urinary retention might be attributed to the changes in the hypothalamus Like the paralytic cough and impaired function of the soft palate, the dyspnoea and state of shock in the last days could be due to disintegration of ganglion cells in the formatio reticularis, nucleus ambiguus and hypoglossal nucleus. Facial paralysis was found clinically on the left side, but histological changes were demonstrated in both facial nuclei The oculomotor paralysis was explained by the severe affection of the oculomotor nuclei.

Case 6 (Rec No. 50,159)

Woman, aged thirty-one, who died three weeks after the onset of illness, seventeen days after admission The illness commenced with headache and fever

On admission the spinal fluid showed pleocytosis, there was high fever, and the flexors of the left hip were paralysed During the following day the patient became unable to raise her head There was commencing respiratory paralysis with decreasing costal respiration, diffuse impairment of the muscle power of both upper extremities and increasing paralysis of both lower extremities, besides paralysis of the bladder

On the day after admission, tracheotomy was performed and manual positive pressure ventilation was instituted On the following day the patient became drowsy, and her left hand and foot were chilly The following day she remained drowsy though she could be roused Seven days after admission she moved her legs a little, especially the right, but not her arms There was a great deal of secretion from the bronchi, and in the last days her face was oedematous, and her blood pressure fell She had high fever throughout her stay in hospital There were repeated difficulties with the tracheal tube, accompanied by poor ventilation The non-protein nitrogen increased terminally Twenty-one days after the onset of illness the patient died in a cyanotic state, but without obvious ventilatory difficulties

Pathology

Sections from the *motor cortex* showed oedema, and vascular stasis, with here and there slight perivascular extravasation of blood There was

swelling of ganglion cells, chromophobia or chromolysis and, focally slight satellitosis, but no signs of inflammation. The hypothalamus showed some swelling of ganglion cells, together with chromophobia and, in the ventral rostral part, slight focal perivascular infiltration with lymphocytes but no inflammatory foci.

In the *mesencephalon*, from which intermittent serial sections were made, no distinct changes were found; nor in the rostral part of the pons. In the caudal region of the *pons* and in the dorsal part of the *medulla oblongata*, both sides presented an elongated focus with recent necrosis, accumulation of lipoid-containing macrophages (microglia) and pronounced hyperaemia with perivascular haemorrhage but only very scanty lymphocytic infiltration. This focus involved the abducens, facial and ambiguus nuclei as well as the dorsal motor nucleus of the vagus and the formatio reticularis on both sides. The hypoglossal nuclei were not affected.

The *spinal cord* showed very pronounced hyperaemia throughout and

inflammatory infiltration, as merely scanty lymphocytes were seen.

Interpretation

The drowsiness of the patient could be attributable to the demonstrated findings in the cerebral cortex and hypothalamus. The marked affection of the medulla oblongata probably explained the respiratory paralysis and cyanosis. The paralysis of the extremities and the bladder present during the last two weeks ante mortem corresponded to the almost total necrosis of the anterior horns of the grey substance of the spinal cord.

To some extent the histological picture in this case differed from that observed in the first five cases, as here it was characterized especially by hyperaemia and necrosis with accumulation of phagocytic microglia cells, whereas true inflammatory infiltration was inconspicuous.

It may be noted that this patient showed severe degenerative tubular changes in the kidneys.

Case 7 (Rec No 51,154)

Man, aged thirty-one, who died after forty-nine days in hospital. On

extremities On the second day the thoracic and diaphragmatic respiration decreased and tracheotomy was performed The patient was first given manual positive pressure ventilation, shortly after the Engström respirator was employed. The blood pressure increased in the first day but later remained normal On the fourth day plugging of the endotracheal tube occurred with anoxia After this the patient presented an 'encephalitic' picture and was shocked Convulsive attacks occurred repeatedly. Later, the patient became unconscious, and the blood pressure increased throughout several hours The following day he gradually became more easy to rouse but his shoulders still felt cold his forearms warm On the sixth day he again responded when spoken to, nodding and shaking his head, and was able to move both corners of the mouth On the seventh day he could knit his brows and voided urine spontaneously From the twelfth day he was clear and attentive From the eighth day there was impairment of kidney function, with increase in blood urea and from the twelfth day paralysis of the cranial nerves was noted During the following days there was frequent accumulation of bronchial secretions and atelectasis of the lungs Gradually he became encephalitic, and all spinally innervated muscles were paralysed, with pronounced atrophy and loss of tonus, together with persistent deglutitory paralysis and periodical attacks of collapse when lying on his side Further, there was hyperpyrexia and falling blood pressure during the last days

Pathology

No definite inflammatory changes were found in the *motor cortex* and *hypothalamus* On the other hand, there were pronounced anoxic changes in the ganglion cells with chromatolysis, swelling or shrinkage of the protoplasm, pyknosis of the nuclei and satellitosis

In the *mesencephalon*, corresponding to the nucleus ruber, substantia nigra and corpora quadrigemina, a focus was found with hyperaemia, moderate perivascular lymphocyte infiltration, microglia proliferation and disintegration of motor ganglion cells while other cells were swollen and chromatolytic Corresponding to both oculomotor nuclei, a similar focus was found, showing ganglion cell degeneration and inflammatory infiltration

Dorsally in the *pons* and *medulla oblongata* similar—partly confluent—foci were seen, involving the abducens and facial nuclei, the motor root of the trigeminal, the dorsal motor nucleus of the vagus the nucleus ambiguus, the hypoglossal nucleus and the formatio reticularis on both sides, whereas the vestibular and cochlear regions, the olive and the white substance were not affected

All the sections from the *spinal* cord showed complete necrosis of the anterior horns, hyperaemia and perivascular haemorrhage in the region affected, moderate numbers of lymphocytes and plasma cells and abundant accumulation of lipoid-containing macrophages In addition, it may be noted that in this patient also the *spinal ganglia* showed inflammatory changes and degeneration of the ganglion cells

Interpretation

The unconsciousness of the patient during the convulsive attacks, the periodically high blood pressure and the hyperpyrexia could be explained as brought about by changes in the cortex and hypothalamus, chiefly anoxic in nature and presumably correlated with the difficulties in ventilation, and the appearance of uraemia. The encephalitic picture was attributable to the demonstrated changes in the substantia nigra region, and the paralysis of the facial muscles corresponded to the destruction of both facial nuclei. The state of shock and deglutitory and respiratory paralysis were attributable to the affection of the formatio reticularis and the vagus and ambiguus nuclei. The paralysis of the spinally innervated muscles was in keeping with the total anterior horn necrosis throughout the spinal cord. Presumably the failing regulation of the temperature of the upper extremities was also of central origin.

This case showed good agreement between the clinical picture and the histological findings. Thus these observations lend support to Bodian's interpretation (Bodian, 1949) of experiments on monkeys: that when the affection has lasted more than one month there is a close correlation between the degree of paralysis and the number of destroyed motor nerve-cells.

Case 8 (Rec No 51,104).

Boy, three and a half years old, became ill on the day before admission, with fever, headache and transitory difficulty in breathing. He died ninety-eight days later

On admission, there was slight fever and pleocytosis; the thoracic respiratory movements appeared weak but the voice was strong On the following day the patient was unable to keep his head up, but the thoracic movements seemed normal, and not until later the same day did paralysis of the right arm appear, together with slight convergent strabismus, paralysis of cervical muscles, beginning deglutitory paralysis, paralytic cough, distinct nystagmus and failing respiration. On the third day the patient became 'encephalitic,' characterized by remoteness, haziness and somnolence There was increase in the blood pressure. Paralysis of the left arm together with beginning impairment of the thoracic respiration was now observed On the fourth day, the encephalitic picture was even more pronounced, with rolling of the eyes and employment of the auxiliary respiratory muscles, but there was good costal and somewhat reduced asymmetrical diaphragmatic respiration. During the following hours the patient had attacks of cyanosis and dyspnoea The voice was now weak, but he seemed able to swallow On account of decreased oxygen saturation

of the blood, tracheotomy was performed and manual positive pressure ventilation instituted

From the eleventh day after admission, the 'encephalitic' eye movements subsided and the patient became more attentive, reacting to slight stimula- [illegible]

respiration for up to ten minutes at a time and from the seventh week respiration improved, so that on some days he was practically free of artificial ventilation On other days, however, atelectasis was noted with accumulation of secretions and fever, so that more prolonged periods of mechanical ventilation were required During a transitory plugging of the tracheal tube, the patient had an attack of unconsciousness and cyanosis. Later, he had repeated attacks of grimacing and myoclonia of face and limbs together with presumably brief spells of unconsciousness There were occasional attacks of tachycardia and profuse sweating

The paralysis of the extremities remained unchanged The encephalitic clinical picture subsided during the last four weeks, while his condition otherwise remained stationary, with repeated attacks of cyanosis associated with collapse during endotracheal suction He died during a technical break-down of ventilation, ninety-eight days after admission

Pathology

Macroscopic examination of the central nervous system revealed in the upper and posterior half of the medulla oblongata a brownish, soft haemorrhagic, necrotic focus, measuring $6 \times 3 \times 4$ mm This focus corresponded completely to the one observed in Case 5 Further, just at the tip of the fourth ventricle, in the midline of the medulla oblongata, there was a small wedge-shaped, greyish, discoloured focus

Sections from the motor region of the *cerebral cortex* showed anoxic changes similar to those observed in Case 7 But no definite abnormality was seen in the *hypothalamus*

Sections from the *mesencephalon* showed moderate hyperaemia, perivascular infiltration with lymphocytes, swelling and chromophobia of some of the ganglion cells in the oculomotor nuclei, but there appeared to be no complete destruction of ganglion cells

In the *pons* and *medulla oblongata* the macroscopically demonstrated foci were seen to be characterized by oedema, maximal hyperaemia, perivascular haemorrhages, slight diffuse perivascular infiltration with lymphocytes, and varying degrees of ganglion cell degeneration, although some ganglion cells presumably capable of function still remained The upper focus occupied the abducens and facial nuclei, and it also involved to a slight extent, Deiter's nucleus and the formatio reticularis with the nucleus

Sections from the upper part of the cervical enlargement of the *spinal cord* showed maximal hyperaemia, pronounced oedema, complete necrosis with disintegration of all ganglion cells, moderate infiltration with plasma cells, macrophages, and marked perivascular accumulation of lymphocytes. In the lower segments of the cervical enlargement the affection was less pronounced and the anterior motor nerve-cells were partially preserved.

Similarly in the lumbar cord, some segments were completely free from inflammatory changes.

Interpretation

As was to be expected from the clinical data—with repeated anoxic attacks and unconsciousness, myoclonia and an intermittent, clinical picture of encephalitis, especially in the beginning of the disease—anoxic changes were obvious in the ganglion cells of the cortex. In conformity with the convergent strabismus and periodical rolling of the eyes, some degenerative changes were found in the abducens and oculomotor nuclei. In the clinical case record no mention was *made of facial paralysis, but both facial nuclei were found to be* involved. The nystagmus undoubtedly was due to the damage of the vestibular nuclei. The partial degeneration of the vagal ambiguus nuclei and formatio reticularis explained the respiratory paralysis and the attacks of cyanosis and dyspnoea. On the whole, the course of the disease indicated that in the beginning of the illness more ganglion cells were damaged and that some of these again became capable of function as the respiratory paralysis was subsiding during the latter part of the illness. The pronounced and persisting paralysis of the upper extremities and the lowered functional capacity of the diaphragm corresponded to the total destruction of the upper part of the cervical enlargement.

Case 9 (Rec. No. 51,732)

Boy, five years old, who died 101 days after admission.

Two days before entering the hospital he became ill with paralysis of the legs. On the day of admission, in the morning, he showed incipient respiratory paralysis and was submitted to tracheotomy (in another hospital) prior to his admission to the Blegdam Hospital.

When first seen, examination showed a high temperature, pleocytosis,

became cyanotic at exchange of the oxygen cylinder and was unconscious for some hours

Seven weeks after admission a definite improvement in his condition was noted and he began to move the upper extremities, whereas the other spinally innervated muscles remained paralytic During the following seven and a half weeks, the condition of the upper extremities improved, and spontaneous breathing reappeared, whereas the lower extremities were still paralytic.

He died suddenly—due to mechanical trouble with ventilation

Pathology

Slight encephalitic changes were found in sections from the *motor cortex* as well as from the *hypothalamus*

In the *mesencephalon* there was moderate affection of the oculomotor nuclei, with some degeneration of the ganglion cells

The *pons* and *medulla oblongata* showed only moderate inflammatory changes Only one focus with marked necrosis was found, corresponding to the right facial nucleus

Sections from the *cervical enlargement of the spinal cord* showed some remaining ganglion cells in the anterior part of the anterior horns The [illegible]

Similar features were seen in various sections from the thoracic cord, whereas the *lumbar enlargement of the cord* showed complete disintegration of the ganglion cells and commencing sclerosis of the entire grey substance as well as of the posterior horns The vessels, however, were still markedly dilated.

Interpretation

This patient, who died 101 days after the onset of illness, because of technical difficulties with artificial ventilation showed clinical improvement of his condition. The histological findings corresponded to the clinical observation that he became able spontaneously to breathe a little and to move his upper extremities, although the lower extremities were still completely paralytic Even if he had lived he undoubtedly would have had persistent complete paralysis of the lower extremities, as all the ganglion cells in the lumbar enlargement of the spinal cord had been completely destroyed

CONCLUSION

This brief survey of our preliminary results does not present any essentially new findings. It gives, however, a comprehensive picture

of the histological changes in the various stages of poliomyelitis—in the spinal cord as well as in the medulla oblongata, pons, mesencephalon, hypothalamus and cerebral cortex.

Comparison of the clinical symptoms with the histological findings presented here shows good agreement. Nevertheless, in the acute stages we met with more extensive histological changes than were to be expected from the clinical findings.

The explanation for this apparent discrepancy between clinical findings and lesions of the central nervous system may be attributed in part to the poor condition of the patients in the acute stage which made it difficult with certainty to register all clinical signs. It should be remembered that in man a considerable number of ganglion cells must be destroyed before paralytic symptoms are clinically recognizable.

HEART

Structural Changes

In thirty-four cases, distinct dilatation of the right heart, especially of the conus arteriosus, was found. Whether or not this was attributable to the positive pressure ventilation method used is a matter of conjecture, but certainly such an explanation cannot be excluded. In nearly all of the cases, moreover, there was considerable hyperaemia of the myocardium In eleven cases we demonstrated more or less extensive haemorrhage subendocardially in the left ventricle, most often in the septum.

True muscle wasting was not demonstrated and thrombi were found only in four cases—of which three were in the right auricle.

Subpericardial petechiae were found in nine cases associated with extensive atelectasis of the lungs.

Microscopic Examination of the Myocardium

In 112 of the 115 cases examined post mortem, five blocks of the myocardium were examined microscopically. The histological changes here varied considerably in intensity.

Hyperaemia	70 cases
Oedema	44 cases
Increase in interstitial cells	30 cases
Muscle fibre degeneration	38 cases
Increase in collagen tissue	17 cases

Thus in about forty-three per cent. of the cases definite pathological changes were demonstrated.

The myocardial lesions can appear very early—even on the second or third day—and for several weeks degenerative as well as reparative lesions may be found.

Hyperaemia was present in nearly two-thirds of the cases, sometimes with diapedesis of erythrocytes This was particularly pronounced in the septum. The subendocardial haemorrhages were *fresh and presumably had developed shortly before death*

Often there was considerable oedema between the muscle bundles as well as between the individual muscle fibres.

An increased number of interstitial cells appeared most often to be accompanied by oedema in limited areas. Among these cells, histiocytes were demonstrated as well as plasma cells and lymphocytes, sometimes also eosinophile cells, and fibroblasts The so-called Anitschkow's myocytes were seen but seldom

Degeneration of muscle fibres appeared as blurring or destruction of cross-striation, fatty infiltration, vacuolization of the sarcoplasm, disintegration of myofibrils, often pyknosis of the nuclei or karyorrhexis. As a rule, the degenerated muscle fibres were surrounded by proliferation of capillary endothelia and fibroblasts, some mononuclear cells and plasma cells.

Most often the degenerative changes involved merely single or very small groups of muscle fibres, which even under low power appeared a little darker and more rich in cells than the other fibres In some cases, numerous small myocardial foci were observed In one case extraordinarily pronounced changes were seen in the myocardium.

Reparative processes occurred in the form of proliferation of fibroblasts and increase in collagen fibrils—in protracted cases, there were streaks of collagen tissue

In most of the cases the processes here described were poorly developed and scattered. We were unable to demonstrate any particular sites of predilection

True pyaemic myocarditis with masses of bacteria was demonstrated only in one case

Among factors involved in the production of the changes observed, anoxia and a direct effect of the virus must be taken into consideration It is well known that the myocardium is sensitive to anoxia It does not seem likely, however, that the histological changes found

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True pyaemic myocarditis with masses of bacteria was demonstrated only in one case.

Among factors involved in the production of the changes observed, anoxia and a direct effect of the virus must be taken into consideration It is well known that the myocardium is sensitive to anoxia It does not seem likely, however, that the histological changes found

are attributable to anoxia alone, since they deviate somewhat from the usual picture of such changes. For example similar changes have not been observed by us in an extensive study of myocardial tissue from patients who had been unconscious for a considerable length of time prior to death; or from patients dying from barbiturate poisoning who had been more or less anoxic on account of inadequate ventilation.

BRONCHI AND LUNGS

Macroscopic Findings in 115 cases

Extensive atelectasis	50 cases
Moderate atelectasis	19 cases
Slight, scattered atelectasis	31 cases
No atelectasis	15 cases
Confluent pneumonic processes	16 cases
Scattered pneumonic processes	14 cases
Mucopurulent bronchitis	35 cases
Marked oedema	66 cases
Moderate oedema	23 cases
No oedema	26 cases

Histological Findings

1 In some cases the entire lungs were air-containing to a normal degree, but in others only parts of the lungs—usually those anteriorly —were normal.

2. Some areas—in particular, those dorsally—were completely atelectatic and showed secondary proliferative processes and induration

3. Catarrhal, fibrinous or purulent pneumonia was found to a varying extent.

4. Oedema and hyperaemia were often conspicuous The alveoli were filled with serous exudate, rich in protein and containing detached alveolar epithelial cells, erythrocytes and scanty leucocytes The capillaries and venules were enormously dilated, engorged with blood, and there was diapedesis of erythrocytes. Alveolar septa were thickened, the alveolar epithelium was proliferating, and sometimes the alveoli were partially filled with fibroblasts.

STOMACH AND DUODENUM

Erosions or ulcerations of the stomach or duodenum were found in eight cases. Their connection with the state of the kidneys is evident from Table XXXII

TABLE XXXII

ec No	Sex	Age	Days of illness	Ulcers of stomach		Renal abnormality noted with naked eye	Nitrogen mg %	Clinical uraemia
				Acute	Chronic			
49 820	M	19	3	+		+	213	
49 822	F	21	27	+				
49 861	M	32	12	+			200	+
48 892	M	27	10	+		–	141	
49 933	M	30	10	+			Not examined	
50 154	M	31	8		+		129	
50 158	F	29	9		+		216	+
50 246	M	39	8	+		–	189	–

In these cases with injuries of the gastric or duodenal mucosa the patients always presented severe changes in the brain stem, especially the hypothalamus.

LIVER

Structural Changes

In the majority of cases the liver was found to be relatively large, congested, and often cyanotic, with a slight increase in consistency In some cases, especially in children, it also showed moderate fatty infiltration, but no macroscopic necrosis.

Histological Findings

In seventy cases the liver was examined microscopically Among these, sixty-two showed congestion and oedema, sixteen slight fatty infiltration and ten scattered areas of central degeneration or necrosis of non-characteristic appearance—changes which were probably due to shock and hypoxia

PANCREAS AND ADRENALS

Neither macroscopic nor microscopic examination revealed any pathological changes.

KIDNEYS

Structural Changes

In eleven cases the kidneys presented demonstrable pathological changes in addition to hyperaemia. The kidney was slightly enlarged, with a tight capsule easy to strip off. The cortex was of considerable thickness, swollen, with indistinct structure. In most cases the cortex was pale, and the medulla was often of a reddish-cyanotic hue. Microscopic examination revealed the presence of nephrosis-like changes. Of the eleven cases, uraemia had been demonstrated clinically in three, anuria in two. In one case precipitation of uric acid in the renal pelvis was found.

Histological Findings

The kidneys were examined microscopically in ninety-one cases, presenting the following changes:

Congestion	72 cases	pronounced in 9 cases
Epithelial degeneration in tubules	24 cases	pronounced in 2 cases
Precipitates in tubules and collecting tubes	21 cases	pronounced in 4 cases

In addition, interstitial oedema and very slight glomerular changes were found in some cases, and calcium precipitates were present in the tip of the pyramids in a few. Evaluation of the total kidney findings showed that, besides the presence of stasis, definite pathological changes were demonstrated in thirty-five of the ninety-one cases examined. The changes varied in intensity. As a rule, the glomeruli were well preserved but often large and hyperaemic. The *proximal convoluted tubules* were often the site of severe changes. In some nephrons the epithelium was of quite considerable size, the cells being large, swollen, with a network of faintly basophil substance, but otherwise the cytoplasm stained very poorly, and appeared hydropic. The brushborder was preserved The cell borders could be distinguished, and as a rule the cells were not detached from the basal membrane The nucleus was round, situated at the base of the cell and normal

in structure. The lumen of the tubule was small. With ordinary staining methods, these tubules appeared very pale, in other tubules the cells took a deep stain—or stained unevenly—with granular cytoplasm Striated arrangement of the mitochondria was seen only seldom The cells were filled with round granules which stained well with Mallory's haematoxylin increasing in size from the base of the cell towards its free surface The lumen varied in width, and often contained a stainable substance. It was considered that some of the changes observed were due to autolysis

The *distal convoluted tubes* showed most often a well-preserved epithelium Many lumina contained precipitates yellowish-red or yellowish-brown in colour, homogeneous or finely granulated. It was not possible to demonstrate destruction of the tubular wall, or necrosis of the basal membrane

The *loops of Henle* and the *collecting tubes* often contained similar precipitates which occasionally nearly filled the lumen The epithelium was well preserved Often there was distinct interstitial oedema, but rarely any traces of infiltrating cells Changes of the wall of the blood vessels were not seen

These changes correspond to what has been described under designations such as lower nephron nephrosis, haemoglubinuric nephrosis, acute tubulo-interstitial nephritis, etc, and it has been claimed that changes of this character may arise in shock from different causes It should be emphasized that a considerable number of these kidneys belonged to patients who had been more or less anoxic for some length of time or in a state of shock The clinical and histological observations in this series suggest that the state of the kidneys resulted from insufficiency of circulation with subsequent damage to kidney function.

That these lesions were demonstrable in our patients, although they do not appear to have been described previously in polio patients, may perhaps be attributed to the circumstance that many of our patients lived long enough for damage to the kidney to develop, whereas patients with shock due to other causes have died earlier

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TABLE VI(a)

MAIN CLASSIFICATION OF THE SERIES DISTRIBUTION AND MORTALITY

Group	Clinical Groups	Principal site of anatomical lesion	Distribution		Deaths	
			No.	%	No	Fatality Rate %
A	Polioencephalitis	*Encephalo-bulbar*	75	22	29	39
B	Pharyngeal and/or laryngeal paralysis without encephalitis, cerebralia or spinal paralysis	*Bulbar*	12	4	3	25
C	Paralysis of respiratory muscles without encephalitis, cerebralia or pharyngeal paralysis	*Spinal*	157	45	50	32
D	Paralysis of respiratory muscles and pharynx or larynx without encephalitis or cerebralia	*Spino-bulbar*	28	8	13	46
E	Paralysis of respiratory muscles combined with cerebralia without pharyngeal paralysis.	*Spino-(bulbar-) cerebral*	60	17	38	63
F	Paralysis of respiratory muscles and pharynx or larynx combined with cerebralia	*Spino-bulbar-cerebral*	13	4	11	85
		Total	345	100	144	42

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